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MEMORANDUM
RM-3436-PR
SEPTEMBER 1963

ECONOMIC VIABILITY AFTER THERMONUCLEAR WAR: THE LIMITS OF FEASIBLE PRODUCTION

Sidney G. Winter, Jr.

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UNITED STATES AIR FORCE PROJECT RAND

The RAND Corporation
SANTA MONICA • CALIFORNIA

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This research is sponsored by the United States Air Force under Project RAND—contract No. AF 49(638)-700 monitored by the Directorate of Development Planning, Deputy Chief of Staff, Research and Development, Hq USAF. Views or conclusions contained in this Memorandum should not be interpreted as representing the official opinion or policy of the United States Air Force.

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PREFACE

This Project RAND Memorandum is a result of RAND's continuing studies of the problems of survival and recovery following thermonuclear war, and particularly of studies of economic recovery after thermonuclear attack, such as P. G. Clark's RM-1809-PR, Vulnerability and Recuperation of a Regional Economy: A Study of the Impact of a Hypothetical Attack on New England (October 1956), and B. F. Massell and S. Winter's RM-2844-PR, Postattack Damage Assessment: A Conceptual Analysis (October 1961). Historical background of recoveries from nonnuclear disasters is provided in J. Hirshleifer's RM-3079-PR Disaster and Recovery: A Historical Survey (April 1963).

The phrase "the limits of feasible production" in the title of this Memorandum is meant to indicate that the present study does not examine all aspects of the problem of achieving viability, but is concerned only with what will be called, for want of a better phrase, the technological features of the problem -- the features that derive from the conditions of production (including the physiological conditions for maintaining the supply of labor) and from the availability of productive resources. In terms of branches of economic analysis, this is the part of the problem for which the theory of production is the most relevant theoretical tool. The highly important questions of economic organization (including the psychological, institutional, social, and political context of economic activity) are not considered, nor are those aspects of the strategic situation, present or future, that determine the magnitude and pattern of destruction that might reasonably be expected to occur in the United States in the event of a thermonuclear war. No predictions are made of the course of economic events after a thermonuclear war; instead a range of situations is considered and that range is discussed in terms of the limits of production, rather than in terms of the actual outcomes given particular organizational arrangements.

It is hoped that this Memorandum will not only be useful to analysts and policymakers in the national security field, but also

will provide an introduction to the topic of postattack economic viability for the benefit of the "intelligent layman." A good deal of material is therefore included with which the professional may be already quite familiar. In particular, the discussion of related studies and of weapon effects, in Section VII of this study, is more detailed than it would be if professional readers alone were being addressed.

In some earlier studies at RAND and elsewhere it has been assumed that extensive postattack economic reorganization could be accomplished within six months or so, and that the surviving resources could be effectively used thereafter. Given this assumption, the main emphasis was placed on the estimation of recuperation time -- the time required for the economy to return to preattack levels of output. The present study fixes its attention on this assumption. It takes the view that the most important question to be asked about the economic consequences of a thermonuclear war is whether the problems of the first two or three years after the war would be manageable, or whether a collapse of the economic system would occur that would bring mass starvation in its wake.

SUMMARY

Preparedness measures that would enhance the short run survival prospects of the population in the event of a thermonuclear war are of no value if the war would so cripple the nation's economic system that the survivors could not be supported in the long run. This Memorandum treats certain aspects of the question of how, and under what circumstances, the resources that would survive such a war could be used to create an economy capable of supporting the population, maintaining its capital stock, and meeting any other national needs of comparable urgency. The main focus is on the limits imposed on production in the postattack economy by the availability of economic resources and the technological conditions of production. The complicated and highly important questions of how economic activity is to be organized, of what combinations of government policy and reliance upon the free market mechanism would assure a close approach to the limits of feasible production, are not treated. A satisfactory answer to those questions must reflect an understanding of the physical-technological problem posed by sudden and massive destruction of economic resources.

"The reorganization problem" is treated in this Memorandum as being synonomous with "the problem of achieving a viable economy." This usage is intended to emphasize the point that a solution to the organization problems of making effective use of the surviving resources is satisfactory only if it is permanent, and the economy does not subsequently revert to a state of chaos and cumulative decline. Such a reversion is not unlikely so long as the economy remains nonviable. For so long as the nation is meeting a significant portion of its essential economic needs out of inventory, it is necessary to consider that inventories might be exhausted before output is adequate to meet those needs. If that occurs, the probable consequence would be a breakdown in the division of labor, resulting in a decline in output, and, ultimately, in catastrophic economic collapse.

In aggregative terms, the process of achieving viability can be viewed as a race between the reconstruction of the capital stock (and thus the recovery of output) and the depletion of the inventories from which essential needs are being met in the meantime. The outcome of this race obviously depends on the size of the surviving stock of productive capacity relative to the stock that would permit essential needs to be met, the rate at which productive capacity can be expanded, the size of the surviving inventories of current non-labor inputs and of goods that can satisfy essential final demands, and the size of these essential demands. At a more detailed level, success or failure in achieving viability is influenced by the composition of the surviving stocks of productive capacity, skills in the labor force and other inputs, and by the geographical distribution of those resources. In addition, it is influenced by the character of the productive processes in which the surviving resources are employed, by the extent of substitutability among inputs and outputs, by economies of scale, and by "technological structure."

"Technological structure" is used here to refer to the set of relationships among resources in the technology that involve dependence on one resource on another, in the sense that the second is an essential, direct or indirect, input to the first. Relations of *self dependence* among resources are of particular importance among the technological determinants of viability, because, speaking loosely, the total loss of all supplies of a resource that is both self dependent and essential to viability would mean that it would be impossible to achieve viability regardless of the extent to which other resources survive. In fact, the entire viability problem is in its simplest form a self dependence phenomenon; essential subsistence goods cannot be produced without labor and the supply of labor cannot be maintained without subsistence goods, and thus the labor force is self dependent.

In addition to providing a reasonably complete characterization of the viability problem at the theoretical and conceptual level,

this Memorandum provides a general quantitative perspective on the problem of achieving viability as it might arise in the United States after a thermonuclear war. Both original results and discussion of some of the most important conclusions of other studies are presented. The former includes an investigation of the probable postattack balance between population and other resource categories that would result at various levels of attack, and an attempt to determine the levels of attack that might reduce the per capita availability of various resources to the danger level. The problems of postattack food supply are considered in some detail, and the problems of the "network industries" -- transportation, communications, and so on -- are discussed briefly.

On the basis of the quantitative perspective described above, some tentative judgments are made as to the levels of attack at which viability would become unlikely in the absence of preattack preparations to facilitate reorganization. The nature of the required preparations and the feasibility of making them are discussed. The dominating uncertainties in the picture are found to be those that have to do with the resumption of agricultural production. In particular, uncertainties about the effects of the war on the ecological balance, and about the implications of ecological imbalances for agriculture, enter the picture at levels and patterns of attack at which the effects of losses in sectors other than agriculture would not be overwhelming. If measures could be devised and preparations made to assure that agriculture would not be drastically altered, then it appears that all other economic problems could be managed. The cost of preparations that would provide reasonable confidence of success in achieving viability depends, of course, on the size of attack anticipated, and in particular on the weight of attack against cities and other economic targets. In very round figures, it appears that a program adequate for attacks of up to 500 megatons on cities (in as many as 100 weapons) might cost up to ten billion dollars, 2000 megatons would put the program in the multiple tens of billions, and over 3000 megatons might well put it in the hundreds

of billions. Even programs at the multiple hundred billion dollar level cannot be rejected as obviously infeasible, given a few years in which to accomplish them. Discussion of the desirability of undertaking such programs, or any program, however, is beyond the scope of this study.

ACKNOWLEDGMENTS

The characterization of the economic viability problem that is set forth in Sections II-VI of this Memorandum emerged in the course of RAND work and discussion on this and related topics during the past few years. Benton F. Massell contributed to this work from the beginning, and both he and Harvey Averch provided useful criticisms and refinements in the early stages of the research of which this study is one product. Their contributions are gratefully acknowledged.

I am indebted to Jeremy J. Stone of the Hudson Institute and Hal Hollister of the Atomic Energy Commission for comments on an earlier draft. Joseph D. Coker and James C. Pettee of the Office of Emergency Planning provided the data discussed in Appendix C, and also made helpful comments on the earlier draft.

Of course, I alone am responsible for any errors that may appear in the final product.

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I. INTRODUCTION

This Memorandum considers the features of the problem of achieving economic viability that derive entirely from the technological conditions of production, including the physiological conditions for maintaining the supply of human labor, and the availability of productive resources.[1] The problems of determining what preattack preparations and postattack organizational arrangements would be most effective in enhancing the prospects for success in reorganization are temporarily set aside. Whatever these arrangements are, a major factor to be contended with is the sudden and massive destruction of economic resources. An understanding of this technological problem is therefore an essential step in determining the nature and extent of the preparations that must be made in order to assure success in achieving viability under various postattack circumstances; it is, of course, only a step. The technological problem must be considered in relation to the proposed organizational solutions before final conclusions can be drawn. Nevertheless, consideration of the technological problem in isolation from organizational factors does provide a preliminary perspective on the total problem. If, as is sometimes suggested, the technological conditions for success in reorganization require "moving the life of the nation underground now, before the attack,"[2] then it may be concluded that the required

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[1]The problem of achieving viability is divided into technological aspects and organizational aspects, and the considerations that determine the amount and composition of the surviving resources under the former category are subsumed, along with the characteristics of techniques of production. This usage emphasizes that knowledge of techniques of production is essential if the implications of particular assumptions about resource survival for viability are to be determined. (The opposite error is less likely to be made.)

[2]This phrase appears in some versions of the "Open Letter to President Kennedy" on the shelter program, signed by professors at many universities. See, for example, the letter in the Des Moines Sunday Register, December 3, 1961, pp. 1-L, 6-L.

preparations are infeasible and/or undesirable, without further inquiry. If, on the other hand, it appears that relatively inexpensive measures would assure the survival of enough resources to support reorganization, and that the primary problem is likely to be making effective use of the surviving resources, then it is necessary to examine whether the obstacles to effective utilization can be so great as to make adequate preparations infeasible.

Ideally, judgments about the technological feasibility of reorganization should be based upon the relations between production possibilities and the resources of the economy; the stock of physical capital in the various forms of structures, equipment, and inventories; the size, skill and physical condition of the labor force; and the geographical distribution of these things. Then, after various assumptions are made as to the amount and distribution of damage to these economic resources that a thermonuclear war would produce, and as to the possibilities for trade with other nations, the extent of the technological obstacles to reorganization under each of the assumed situations could be determined. However, the theoretical and empirical basis for such a definitive analysis of the problem does not exist at the present time.[1]

There is, of course, a good deal of information available that describes, or purports to describe, the technological relations between inputs and outputs in the economy as a whole, in particular industries, and in particular processes. There are statistically fitted aggregative production functions, typically distinguishing only labor and capital as factors of production,[2] for the economy as a whole and for individual industries. There is input-output analysis, which may distinguish a large number of different industries in the economy, and which focuses on the problem of determining the

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[1]There is some reason to think that it may be unattainable in principle. See the discussion in Section V.

[2]That is, all labor and all capital are treated as homogeneous, and lumped into two aggregates.

interindustry distribution of total demand[1] implied by a given interindustry distribution of final demand. There are models of production processes in individual industries, often based on engineering or experimental data.[2] These models may distinguish quite a great number of alternative production methods, indicate substitution possibilities among different materials, types of equipment, and so on. There are various systems for analysis of supply requirements, that is, for determining whether a particular material or type of capacity is or is not likely to be a bottleneck if an attempt is made to carry out a given production program. Analyses of this type are similar to input-output analysis in the emphasis on the generation of indirect requirements, but do not attempt an integrated and comprehensive view of the entire economy. As a result, more technological detail can be considered. Finally, of course, there is a good deal of information that is not cast in any systematic framework, such as simple statements that one sort of substitution or another is feasible. All of these methods of analysis and types of information can be useful, and some are essential, in investigating the problems of achieving economic viability.

Unfortunately, none of the methods mentioned above can illuminate more than a limited part of the question of the technological feasibility of reorganization. Studies of individual industries or processes, in isolation from the rest of the economy, can be informative. But it is obvious that the interrelations among industries are of fundamental importance. Consider, for example, the problem of restoring the production and distribution of food after a nuclear attack. How fast this might be accomplished depends on the availability of tractor fuel, and therefore on the situation with respect to petroleum and natural gas, and on the magnitude of the competing demands for them.

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[1]Total demand on an industry equals final demand plus intermediate demand, the latter representing the use of the industry's products as current inputs in other industries.

[2]As in the case of some production functions that have been developed for agricultural products.

An investigation of this situation might lead to the conclusion that a shortage of tractor fuel would seriously delay the resumption of agricultural production unless some refineries could be built, or damaged ones repaired, within a certain period. This in turn would lead to an investigation of the status of the industries producing materials and equipment needed in the construction of refineries, then to a consideration of the suppliers of inputs to these industries, and so on. Clearly, a very large section of the economy would have to be considered before the possibility that a bottleneck at some earlier stage might delay the resumption of agricultural production could be excluded *a priori*, the more so since competing demands on capacity, and alternative ways of meeting those demands, must be considered at every stage.

Only input-output analysis, among the techniques that have been empirically implemented, deals with the complex relationships of the industries in the economy in a comprehensive and systematic way; but at the present stage of development of input-output technique, the simplifying assumptions that must be made to make statistical implementation possible are very strong, to the point where aspects of reality that could easily be crucial determinants of success in achieving viability are assumed away. In particular, the geographical distribution of economic activity, the structure of leadtimes in production processes, and the existence of alternative techniques of production are treated sketchily or not at all. Furthermore, even the largest input-output matrices do not begin to approach separate treatment of each of the readily distinguishable goods and services in the economy. It can be (and is) argued that these simplifications do not necessarily negate the usefulness of the input-output technique, since the errors introduced by ignoring these aspects of reality may be quantitatively insignificant, or, if not insignificant, small relative to the errors resulting from the use of alternative techniques. But the errors are not likely to be small where the relative amounts of different types of capacity

in the economy differ drastically from the amounts that would be ideally suited to producing the desired output mix; the geographical distribution of transportation capability may bear little relation to the geographical distribution of other activities; and the urgency of obtaining particular outputs by particular times creates a complex and unprecedented pattern of time preferences for different goods -- conditions that might well be produced by a thermonuclear war.

In sum, a definitive quantitative analysis of the special economic conditions that would characterize the first months and years after a nuclear war would require a degree of detailed knowledge of the capabilities of the economy that is simply not attainable at present.[1] The conclusions of any investigation of the prospects for achieving viability, therefore, are subject to great uncertainties even in relation to the characteristically great uncertainties that attend any economic predictions. Major improvements in understanding the problem are possible only if important simplifications can be made. Such simplifications might be based on some insight into the special character of the problem of achieving viability, as distinguished from other problems in the efficient use of resources. Or it might be possible to reduce or eliminate some of the major uncertainties by an appropriate choice of policy measures; indeed, the principal rationale of some policy measures may be not that they yield a calculable improvement in the outcome, but that they make the outcome calculable.

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[1]It should be mentioned that the PARM model, under development by the National Planning Association for the Office of Emergency Planning, represents an advance by orders of magnitude in the sophistication of input-output techniques -- so great an advance that the model is hardly of the same genus as, for example, the description of the economy provided by a 44 sector input-output maxtrix and its inverse. It is clear that this model, when completed, will make possible an enormous advance in our understanding of the viability problem. Nevertheless, most of the reasons given above for believing that input-output calculations may yield quite misleading indications of the difficulty of achieving viability will apply, in some degree, to PARM calculations.

Although predicting the economic situation after a hypothetical thermonuclear war poses a severe challenge to present knowledge of the economy and how it functions, it is not implied that no useful conclusions whatever can be drawn. At the extremes of the range of situations covered by the term "thermonuclear war," considerable confidence can be attached to conclusions about the feasibility of reorganization, in spite of the limits of understanding. It is difficult to believe, for example, that reorganization would be infeasible (for technological reasons) after a war in which weapons with a combined yield of less than one hundred megatons were detonated over the United States.[1] The physical change produced in the country as a whole by a war of that intensity simply could not be great enough to make the recovery of the economic system technologically infeasible. At the other extreme, a war in which severe thermal and/or radiological effects covered essentially the entire area of the country, and in which a substantial fraction of the country was covered by blast effects as well, would make it impossible to restore production of necessities in time to support the survivors.[2] These conclusions are useful because situations at these two extremes actually could arise in the course of the present decade. But there is still a wide range where it is difficult to assess the prospects for reorganization, and a substantial narrowing of this range will be impossible without a better conceptual understanding of the viability problem.

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[1]This statement assumes that the individual weapons involved are large, so that the number of weapons involved does not exceed, say, twenty-five. Because of the two-thirds power scaling law relating area coverage to weapon yield, a given total yield does much more damage in small packages than in large. And, of course, the uneven geographical distribution of wealth and population greatly magnifies this effect.

[2]This statement could conceivably be false if extremely elaborate preparations were made to "move the life of the nation underground." On the other hand, the statement about the possibility of reorganizing after a one hundred megaton attack could also be false, if entirely unexpected effects on the economy somehow developed. The uncertainties in both statements are considered to be negligible.

One of the objectives of this study is to set forth some of the most important facts bearing on the problem of restoring the United States economy to viability after a nuclear war, to suggest some preliminary conclusions about the feasibility of accomplishing this under various postattack conditions, and to identify the major uncertainties that exist at the present time. But a more fundamental objective is to provide a reasonably complete characterization of the problem at the conceptual level, in the hope that such a characterization will yield some fundamental simplifying insights and thus suggest fruitful lines of inquiry for future studies. The quantitative and factual discussion reflects this more fundamental objective. The focus is on what are believed to be the central features of the problem, and very rough-and-ready quantitative information is presented on those features rather than a more systematic (and more defensible) treatment of details. It is certainly not meant to suggest that careful treatment of details is unnecessary, or that this study is a substitute for more detailed investigations. But the very fact that thorough study of narrower issues is possible sometimes seems to militate against investigation of the problem as a unified whole, with the result that conclusions about the total problem are either dominated by the narrow studies, or are based on arguments that are even more intuitive and impressionistic than they need to be.

The discussion that follows contains both tentative generalizations and enough in the way of specific details and examples to give those generalizations some content and support. It progresses at several different levels. Section II provides a brief sketch of the possible paths that economic events might take after a nuclear war. It is hoped that this section will assist the reader to accomplish the painful and difficult mental feat of regarding a nuclear war as something that might happen, and might result in a total and more or less permanent collapse of the economic system (or might not, depending on the weight of attack, the preparations made, and so on). Section III characterizes the achievement

of viability as a problem of restoring the nation's stock of capital to the level required to supply the surviving population with adequate essential consumption goods, within the time allowed by the surviving inventories. A formal theoretical treatment of this aggregative view of the problem is given in Appendix A. Section IV is, in a sense, a critique of Section III, a catalog of the various reasons why a simple calculation of the amount of surviving real wealth per capita might be misleading as an indicator of the difficulty of achieving viability; it is quite obvious in general terms that such a calculation would be of limited value. But it is useful to have a clearer picture of the reasons why this is true than is provided by a general reference to chaos, bottlenecks, disrupted transportation and communications, and so on. Section IV sets forth the reasons why the surviving wealth of the nation will not be ideally suited to supporting the effort to achieve viability, whereas Section V considers those aspects of the economy that determine how quickly the distortions produced by the war could be adapted to, reduced, or eliminated. Some of these considerations are treated in formal terms in Appendix B. Section VI examines relationships between the technological determinants of viability and various questions of national policy that must be decided in the process of planning and carrying out the reorganization effort. Section VII provides a general quantitative perspective on the viability problem as it might exist in the United States after a nuclear war, and summarizes some of the most relevant facts that bear on the problem. Also in this section are conclusions as to the probable consequences for economic viability of attacks of various total weights and various weights on urban-industrial targets. Appendix C contains some technical details relating to the calculations in Section VII.

II. THE POSTATTACK ECONOMY: THREE PHASES OF RECOVERY

During the war, and for a period of a few weeks or months following it, the principal task facing the nation will be to assure the survival of as much of the population as possible. This is, of course, the main objective of civil defense activity in the narrow sense: dealing with a wide range of threats from the blast, thermal, and radiation effects of nuclear explosions; from continuing fire and radiation hazards; and from exposure, disease, thirst, and starvation. The success of the efforts made to meet these threats will depend almost entirely on preparations made before the war, such as stockpiling of medical supplies, food, and other survival items, the development of large, adequately trained, and effectively organized civil defense cadres and, above all, preparation of adequate shelter space. New production will play a minimal role in the support of the activities being conducted. Even if a significant amount of new production were possible during this time period, the urgency of the requirements would be such that not enough could be produced in time to make a significant difference to population survival. Needs will have to be met out of surviving inventories, that is, from the resources of areas that escape damage or are damaged only slightly. The major problems will be in developing the transportation, communications, and organizational capabilities required to bring these resources to bear at the points where they are needed.[1] In view of the overriding importance of meeting immediate threats to millions of lives, it is unlikely that much effort will be made to conserve resources for meeting possible future requirements; and together with little or no new production, this implies that inventories of some items are likely to decline rapidly.

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[1]With the exception of medical supplies, there is unlikely to be a nationwide shortage of essential consumption goods during the survival period. The nation is well endowed with stocks of most of the necessities of life, but distribution will be a serious problem. In some cases (for example, housing), it will be necessary to move the people rather than the resources.

By about two months after the attack, there will be a great reduction in the number of people whose survival is not assured, either because immediate threats were successfully handled, or because many people had died. At that time, the dwindling inventories of various essential commodities will signal the existence of a longer term threat to survival. Unless production of the necessities of life can be resumed, whatever success there has been in protecting the population from the immediate consequences of the war will dissipate as supplies of food, medicines, and heating oil disappear; the surviving thermal generating plants exhaust their supplies of coal and fuel oil; and starvation, disease, and exposure take their toll.

It is at this stage that the most formidable organizational problems will present themselves. Even if the plant and equipment, the skills of the labor force, and the transportation and communication systems are fully adequate for winning the race between the recovery of output and the depletion of inventories, a failure to achieve viability could easily occur if these resources are not effectively marshalled. The plans, the authority, the effective organization, and the general overview of the situation may not exist, particularly if the nation's capital and some state capitals are destroyed in the war. And the "invisible hand" that guides activity in our market economy is likely to be paralyzed by immense uncertainties as to property rights (as a result of the destruction of physical assets, securities, records of transactions, and financial institutions); the breakdown of the monetary system; the destruction of organized exchanges; and the shortages of communications.

Localized attempts at constructive action are virtually certain to occur, and some may be effective in buying more time for the reorganization effort. For example, food processing plants and electric generating stations might well continue to produce in spite of uncertainties about the legal and financial implications of doing so.

Effective rationing of food supplies might spring up spontaneously in some communities.[1] But such localized attempts at dealing with the situation would not suffice to restore the economy of the nation as a whole to viability, for restoration would require the reestablishment of a system of interregional flows of goods and services.[2] Many tasks of physical reconstruction would be beyond the resources of any local organization (in the absence of normal supplies of materials),[3] and there would have to be some sort of national solution to the legal and financial problems standing in the way of economic activity. A solution to the reorganization problem in the nation as a whole would be possible only on the assumption that the localized efforts would somehow coalesce into a single unified effort, or that the federal government would retain (or could acquire) the requisite capabilities after the war.

It is certainly possible that separate centers of reorganization activity in various states and localities would gradually coordinate their efforts into something approaching a unified national effort. However, it is also possible that these separate centers would conflict with one another, and inhibit rather than support each other at their point of contact. Among the stresses and strains of the survival period and the following months will be some of a political nature. Deep conflicts of interest will certainly exist among the surviving populations of different regions, and perhaps among different groups

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[1]A very interesting fictional account of the course of economic events in a community that escapes direct damage in a nuclear war is given in a novel by Pat Frank, Alas, Babylon, Bantam Books, New York, 1959.

[2]It is believed that if a viable economy could be created in the United States on the basis of the self sufficiency of small regions, it could be accomplished only after a period of tremendous chaos and population losses in areas in which agricultural output is at present well below what would be needed to support the population.

[3]Perhaps more important, local organizations (public or private) would often lack the incentive to take steps essential to the viability of the economy as a whole, because these steps would be valueless in the absence of coordinated complementary action.

in the same region. The most fundamental of these will relate to the distribution of the inventories of food, shelter, and other necessities. A region that happens to possess a large food inventory may be reluctant to share it with another less favorably situated region for fear that new supplies will not be available in time to forestall severe shortages. The homeless are likely to favor some compulsory system for equitable sharing of the surviving housing, whereas those still in possession of their homes may resist such a system. The extent to which such conflicts of interest will produce conflicts of policy among governmental units is hard to estimate. Much will depend on the preattack preparations (which in turn will depend on the extent to which the possibility of such conflicts is explicitly faced); on the perceived seriousness of the postattack situation, including the likelihood of eventual reestablishment of federal control; and on the way in which the limited capabilities of the federal government are exercised. But it is clear that the potential would exist for conflicts that might imperil the success of the national reorganization effort.

For present purposes, it will simply be assumed that the federal government would be capable of initiating and guiding the national reorganization effort. Such an assumption does not dispose of the problem, for it would take time to accomplish sufficient physical reconstruction to permit the economy to meet all essential needs out of current production. However long it takes, the resources needed to support the population and to carry on the process of reconstruction would, in part, have to come out of inventory. For example, if a large part of a year's agricultural output is lost as a result of fallout contamination and the disruption of farming activity produced by the war, inventories must be drawn upon to feed the population until the next year's harvest is in. If contamination of farmland or a continuing shortage of tractor fuel results in a harvest far below normal, the food inventory must suffice for still another year.

The reorganizing economy faces critical deadlines. If inventories of items essential to the support of the population or to the

reconstruction effort are exhausted before production is adequately restored, the reorganization effort will fail. The health and vigor of the population and the willingness and ability of the labor force to continue to engage in productive efforts will be adversely affected as supplies of the necessities of life fall to or below minimum requirements. Output will then decline, both as a result of the weakened condition of the labor force and of the inevitable rise in absenteeism as individuals attempt to meet their own and their families' needs by foraging, plundering, or selling their household goods. Ultimately, there will be a complete cessation of organized national effort towards long term reconstruction. It will become progressively more difficult to maintain order. Immediate threats of starvation, disease, and exposure will soon reappear; but there will be no inventories with which to meet these threats, no period of grace while a permanent solution is found. The result will be a catastrophe, perhaps of the same order of magnitude as the war itself. If the catastrophe is held within limits, it will be because time for further reorganization has been purchased for some portion of the population at the expense of another portion, perhaps because regions with relatively large food supplies will refuse to support less fortunate regions.

If all of the critical bottlenecks are removed and essential production is resumed before inventories are depleted, the reorganization period will have come to a successful conclusion and the stage will be set for recuperation. Severe imbalances and bottlenecks may still characterize the economy, however. Capacity of various kinds may stand idle for want of raw materials, electric power, transportation, or manpower; damaged capacity will await repair; but the economy will be capable of sustaining the population. Imbalances and bottlenecks will then represent, not a threat to viability, but rather an opportunity for a rapid growth of output. The productivity of new investment will be very high, since the new investment will provide, in one situation after another, the missing link in the chain, or the keystone of the arch. The rate at which the economy

recuperates will, of course, depend on the proportion of output devoted to investment. It might happen that the nation as a whole would be reluctant to forego current consumption, and recuperation would progress very slowly, at least for several years after the war. A situation of this kind is more probable if the levels of per capita consumption at which viability was achieved were low. More important, current consumption might seem preferable to investment if (contrary to the statements above concerning the productivity of new investments) the pattern of economic activity at the end of the reorganization period were such that a very large amount of investment would have to be completed before any increase in output could occur. Such a situation might arise if viability required great shifts of labor into agriculture and the abandonment of much of the surviving industrial capital. Finally, recuperation would be slow if national security expenditures made major demands on the nation's output. If, on the other hand, the nation were willing and able to forego consumption long enough to get recuperation under way, and then to devote a large share of the increment of output to investment, recuperation might be rapid.[1]

It has been argued above that, since certain tasks must be accomplished within certain limits if the economy is to achieve viability, a period of <u>apparent</u> success in marshalling the nation's resources may be followed by renewed chaos, crisis, and economic collapse from

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[1]Discussion of just how rapidly recuperation could proceed is beyond the scope of this study. However, the question of whether a rapid recuperation rate would be <u>feasible</u> is not the same as the question of whether it would be <u>desirable</u>. The postponement of a given amount of noninvestment expenditures involves a real sacrifice, which may or may not be adequately compensated for by the benefits of more rapid recuperation. Investigations of the feasibility of particular recuperation rates are still of interest, since they do illuminate the range of choices that would be open to the nation. Economic policy during the reorganization period will be influenced to some extent by views on the rate of recuperation that would be feasible and desirable; this point is examined in Section VI.

which there is no escape. It is for this reason that the terms "success in reorganization" and "success in achieving viability" are used interchangeably. The ultimate survival of a large fraction of the population, and, in fact, the existence of the nation itself, may be very sensitive to the degree of success in coping with the problems of organizing economic activity. So long as the nation is meeting a significant fraction of its essential needs out of inventory, there will be a possibility that the depletion of inventories will lead to renewed strains on economic organization -- strains that could turn out to be overwhelming. And so long as such a possibility exists, the principal criterion by which postattack economic policies should be judged is their effect on the probability of success in achieving viability.

The possibility that ultimate economic collapse may be preceded by temporary success is a distinctive and generally ignored feature of the economic consequences of a thermonuclear war. Certain considerations combine to support the view that it is a realistic possibility, in spite of the absence of any obvious parallel for such a pattern of events. Large inventories of many commodities, and particularly of food, would undoubtedly survive even a massive attack on the United States. However, agriculture is vulnerable to thermonuclear war in qualitatively different ways from its vulnerability to conventional warfare. Serious difficulties might be encountered in restoring agricultural production even if manpower and all of the preattack inputs to agriculture from the industrial sector were in abundant supply.[1] Finally, it is quite likely that a thermonuclear war would not be preceded by the sort of lengthy period of all-out economic effort that characterized the historical instances of collapse of a national economy.[2] This has important implications

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[1]See Section VII.

[2]These historical instances have generally been a part of the aftermath of long wars -- very long wars by the standards of what may be expected in the thermonuclear age. See the interesting treatment of some of these cases in J. Hirshleifer, The Economics of Disaster: A Historical Survey, The RAND Corporation, RM-3079-PR, April 1963.

with respect to the achievement of at least a temporary economic recovery; physical capital not destroyed or damaged in the war would be in normal condition, inventories would be at normal levels, and so forth. The inputs to support a temporary recovery would certainly exist; but the actual achievement of viability might be, for strictly technological reasons, a good deal more difficult.

III. AN AGGREGATIVE ANALYSIS OF THE TECHNOLOGICAL CONDITIONS

Following is a systematic discussion of the technological factors that determine whether reorganization is feasible, or whether a temporary and localized recovery of output will necessarily be followed by general and catastrophic decline. First is a precise definition of economic viability: An economy is viable if it is functioning, and capable of producing, without external aid, an output sufficiently large and appropriate in composition to:

(a) provide its workers and their families with a level of consumption high enough to maintain their productivity and to give them the incentive to continue to contribute their services to the economy in a socially productive way;

(b) meet any fixed[1] claims on its output that may exist;

(c) maintain the stock of real capital (including inventories) required to accomplish (a) and (b).

The economy is very unlikely to be able to satisfy these conditions when it emerges from the war and the survival period. The postattack reorganization problem is defined as the problem of converting the surviving resources of the economy into a viable economy; and the reorganization period is defined as the period beginning when the immediate threats to population survival created by the war have largely subsided, and ending when viability is achieved.[2]

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[1]"Fixed claims" refers to claims that, as a matter of national policy, would be met even if the result were a failure, immediate or in the long run, to accomplish (a) above. For example: (1) burdens of national security -- perhaps the enforcement of the terms on which the war ended, or an attempt to rearm, and (2) support for non-productive elements of the population -- the disabled, or persons living in areas where it is impossible, for the time being, to resume economic activity. See Section VI.

[2]Alternatively, it might be said that reorganization has been accomplished when it is a virtual certainty that viability will be achieved at some time in the future. However, if reorganization is close to the margin of technological feasibility, uncertainty about the outcome is likely to persist almost to the time when success is actually achieved.

To discuss the factors that determine the success or failure of the effort to achieve viability, it is useful to begin by examining the problem in a highly simplified form. If the effects of the war on the social arrangements by which economic activity is guided are disregarded, the remaining effect on the economy is the destruction of productive resources, including population losses. If it is assumed that the population at the end of the survival period would be capable of operating a viable economy,[1] the reasons why the economy might not be viable at the end of the survival period are narrowed down to the fact that certain essential portions of the nation's capital stock, including the stock of skills in population, may be missing as a result of the war.[2] Assuming that the amount and pattern of destruction is such as to produce this result, the task of achieving viability is the task of recreating essential missing portions of the capital stock from whatever resources are at hand. It will be technologically possible to accomplish this task if the surviving capital stock (including inventories and skills) is sufficiently large and appropriate in composition to make it possible to:

(a) restore the capital stock to a level and composition consistent with viability;

(b) meet any fixed requirement that may exist;

(c) support the members of the labor force and their families at a level sufficiently high to prevent a significant reduction in the labor supply available for the reorganization effort.[3]

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[1]That is, if the surviving population would not be so afflicted with mental and physical disabilities that it would be incapable of supporting itself even if supplied with the best possible stock of plant and equipment.

[2]Although this discussion focuses mainly on the problems resulting from the destruction of physical capital, much of the analysis applies equally to capital in the form of acquired abilities of the labor force. As in the case of physical capital, particular skills that are in short supply as a result of the war may be producible (through education and training) during the reorganization period, at some price in terms of other resources.

[3]For a discussion of the meaning and implications of the phrase "available for the reorganization effort," see Section VI.

To bring out the central features of the technological problem of achieving viability, the following simple model of the situation is set forth:[1]

(1) Labor (L) and productive capacity (K) are treated as homogeneous aggregates, ignoring the diversity of types of physical capital and of skills in the labor force.

(2) Productive capacity may be used (in conjunction with labor) to produce either more of itself or to produce food, and the production functions for the two are identical.

(3) The economy has, at the end of the survival period, an inventory of food (S) in excess of the amount necessary to the smooth functioning of the distribution system for food -- the latter amount being treated as a part of the homogeneous stock of productive capacity.

(4) The continued availability of the services of each member of the labor force depends on his receiving a certain well-defined amount (c) of food in each time period and there is no other subsistence consumption requirement. Furthermore, the available food supply in any time period will be equitably distributed; consumption requirements will be met for all workers or for none.

(5) The productivity of labor is an increasing function, $p(\frac{K}{L})$, of the amount of productive capacity per worker, and depends on nothing else.[2] Furthermore, $p(0) < c$, a unit of labor cannot produce its own subsistence if it has no capital.

(6) Depreciation reduces the stock of productive capacity by a certain fraction (d) at the end of each time period, but the storage of the food inventory is costless.[3]

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[1]See Appendix A for a more complete and systematic treatment of this model.

[2]It is also assumed that $p(\frac{K}{L})$ displays nonincreasing marginal returns, that is, $p''(\frac{K}{L}) \leq 0$.

[3]For simplicity, it is also assumed that $p'(\frac{K}{L}) > d$ for all $\frac{K}{L}$, so there is always some net return from additional capital.

(7) There is a fixed requirement (R) which must be met in each time period, and which cannot be met out of the food inventory; it is treated as a requirement for capital goods. This requirement is fixed both in amount and in the sense that it will be met even if the consequence is a failure to make good the depreciation of the stock of productive capacity, or the subsistenace needs of the labor force.

Corresponding to any labor force L and fixed requirement R, there is some minimum level $\bar{K}$ of the stock of productive capacity that permits an output to be produced that is just adequate to meet the subsistence needs of the population, the fixed requirement, and the replacement of depreciated capital. That is, $\bar{K}$ is the solution to the following equation in K:

$$Lp(\frac{K}{L}) = cL + dK + R$$

The model economy is nonviable if the stock K_o at the beginning of the reorganization period is less than $\bar{K}$. In this case, the economy cannot simultaneously support its workers, meet the fixed requirement, and maintain the capital stock. If K_o is less than $\bar{K}$ and the initial food stock S_o is zero, the economy faces inevitable collapse. It might be possible to meet the subsistence and fixed requirements temporarily, but only by consuming capital -- by failing to provide for depreciation. Eventually, productive capacity would decline to the point where even these requirements could not be met, and collapse would follow. If K_o equals $\bar{K}$, and the food stock is zero, the economy is capable of maintaining itself, but not of recuperating; it stagnates.[1] However, if there is a positive initial food stock, some time is afforded for building up the capital stock, and

[1]The case of stagnation cannot realistically be regarded as a mathematically precise, technologically determined boundary between collapse cases and recuperation cases. "Subsistence" and "fixed requirements" and "depreciation" would not in fact be precisely determined claims on output. Stagnation may or may not occur, but it will not occur simply because the surviving capacity is too small by one dollar, or one billion dollars.

it may be possible to avoid collapse even when K_o is less than $\bar{K}$. To be precise, S_o/cL time periods are available for building the capital stock to or above $\bar{K}$, where S_o is the food inventory at the end of the survival period.[1]

The question is, is this enough? The answer depends on all the factors in the problem in a way described diagrammatically in Fig. 1. Capital and food are measured in the vertical axis, time on the horizontal. (Since capital and food have identical production functions, a unit of each can be regarded as having the same value, and they can be measured on a single axis.) The declining straight line shows the course of the remaining food stock over time; it starts from S_o, the initial food stock, declines at the rate cL per period, and reaches the axis at time $t_v = S_o/cL$. The solid curved line describes a case of success in achieving viability. It reaches the ordinate value $\bar{K}$ before it reaches the abcissa value t_v. Hence, when time t_v arrives, the capital stock is more than adequate to meet all the requirements on output with some surplus left over to generate a further expansion of output.

The broken curved line represents a course of events that ends in collapse of the economy. There is a temporary recovery in current output while the labor force is supported out of the food inventory, but when that inventory is exhausted the capital stock is less than $\bar{K}$. This means that the output that can be produced from this capital stock is not sufficient to provide for depreciation, subsistence, and the fixed requirement. Something must give, and it is assumed that depreciation on the capital stock will be the first thing to be sacrificed. The capital stock will therefore begin to decline, and after a time it will decline to the point where the output that can be produced is less than subsistence plus the fixed requirement. By definition of the fixed requirement, the next claim on output to be sacrificed will be subsistence. There will therefore be a decline in

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[1] For simplicity in this discussion of what is formally a difference equation model, we assume that S_o/cL is an integer.

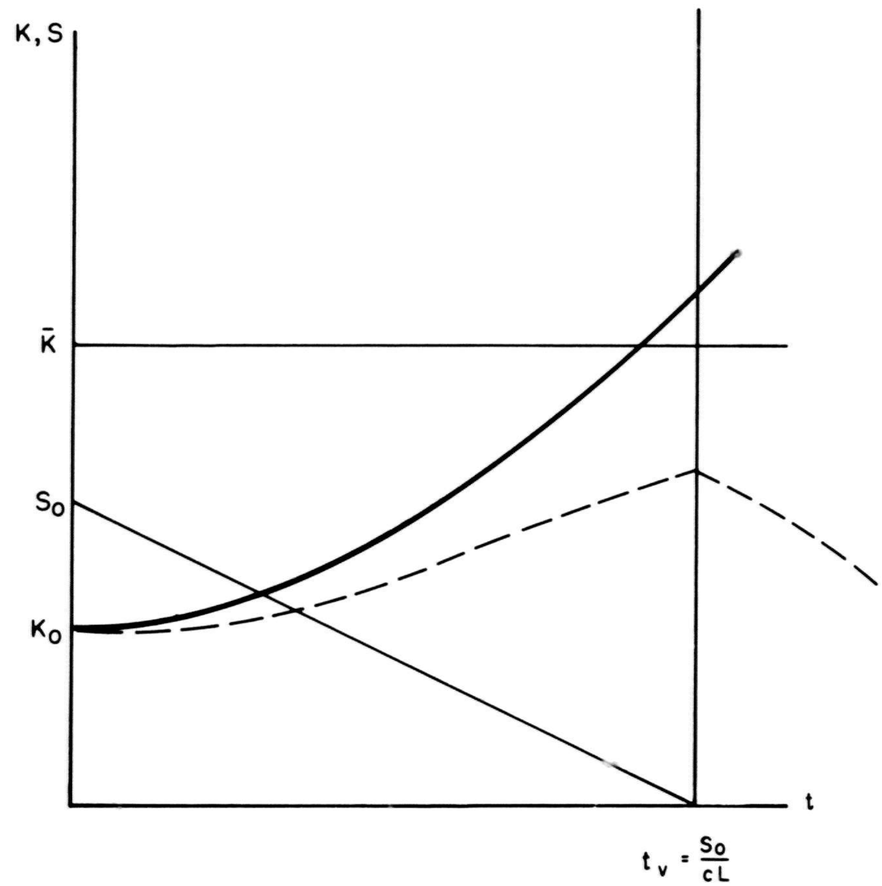

Fig. 1 — Success and failure in achieving viability

K = Productive capacity

S = Inventory of food

L = Labor

$\bar{K}$ = Productive capacity required for viability

S_o = Food inventory at end of survival period

K_o = Productive capacity at end of survival period

t_v = Time of depletion of food inventory

S_o/cL = Ratio of food stock to food requirements per period

the labor supply, and this will produce a further decline in output. So long as the policy followed is to devote to subsistence all output that is left over after the fixed requirement is met, there will be a cumulative decline in the capital stock, the labor supply, and output.

According to this model, there is a sharp discontinuity in the relationship between the ultimate state of the economy and the amount of surviving productive capacity, given the size of the surviving labor force and the food stock. When surviving capital is reduced below a certain critical point, the result is a failure to achieve viability by the time the food stock is exhausted, and this means that the collapse of the economy inflicts large population losses in addition to those caused by the war. This conclusion depends essentially on the assumption that, as a matter of policy or as a result of the functioning of the uncontrolled market system, providing for subsistence in the short run has a higher priority than providing for depreciation. Given that the capital stock is below $\bar{K}$ when the food inventory is exhausted, a cumulative decline can be avoided or brought to a halt only if at some point the capital stock is held essentially constant or increased while the labor supply is allowed to decline as a result of inadequate provision for subsistence.[1] Of course, the conclusion that such a sharp discontinuity exists also depends on the fact that the model makes no allowance for random influences on the economy. If such allowance were made, the <u>probability</u> of a failure to achieve viability would be a continuous function of the surviving capital stock, rather than shifting abruptly from one to zero.

The central technological features of the viability problem may be summarized in the terms of this simple model: Let K* be the value of K satisfying the equation

$$L\ p\ (\frac{K}{L}) = dK + R$$

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[1]In principle, the declines in the capital stock and the labor supply might be brought to a halt simultaneously, but this would still imply that an almost adequate provision for depreciation was being made while the labor supply was declining.

If K_o is less than or equal to K*, there is no possibility of achieving viability, regardless of the size of the food stock, because the fixed claim on current output is so large that capital must be consumed in order to meet it. Productive capacity declines from the outset, and the system collapses. If K_o is greater than K*, however, a sufficiently large food stock S_o will always permit reorganization to be achieved, given all the other parameters of the model.

In the context of this simple model, an increase in the surviving labor force, given all other parameters, has three distinguishable effects on the prospects for achieving viability.[1] The first, which is clearly unfavorable, is that the food stock is exhausted at an earlier date. The second is that the level of $\bar{K}$ is affected. For small values of the fixed requirement, this effect is also unfavorable because subsistence for a larger number of workers can only be provided with a larger capital stock. However, if R is sufficiently large, it can happen that the assistance the larger labor force provides in meeting the fixed requirement outweighs the effect on subsistence requirement, and $\bar{K}$ is reduced. An actual situation of this type might be one in which the fraction of the population surviving the war were much less than the fraction of productive capacity, and the nation faced a continuing external threat. Higher levels of population survival would make it possible to use the surviving capacity, and eliminate the requirement that would otherwise exist for additional, highly labor-saving productive capacity. The third effect is unambiguously favorable: the productivity of capital is increased with the result that the growth curve of the capital stock rises more rapidly. The net result of these three effects cannot be deduced without more precise information on the function $p(\frac{K}{L})$, the initial values, and the other parameters of the problem.[2]

[1] If the model allowed for such facts as the nonhomogeneity of the labor force and the presence of indivisibility in some productive processes, the apparent implications for viability of higher population survival would be more favorable than is indicated here.

[2] See the more extensive treatment in Appendix C.

An increase in K_o, an upward shift in the function $p(\frac{K}{L})$, or a decrease in c or d would obviously improve the prospects for achieving viability, as would a decrease in R. It should be noted, however, that the economy could still be rendered nonviable by a sufficiently large loss of productive capacity relative to the population that must be supported, even if R were zero. (This follows from the assumption that the labor force cannot support itself if it has no capital to work with whatsoever.) The earlier discussion of the sequence of events ending in collapse may apply even if subsistence and depreciation are the only claims on output.

If the achievement of viability is not just on the margin of feasibility, consumption may be above subsistence levels or other claims on output may be satisfied (in addition to the fixed requirement), without endangering the success of the reorganization effort. The result of such departures from a policy strictly oriented to achieving the maximum possible increase in capacity would be simply to reduce the gap between actual capacity after viability is achieved and essential capacity $\bar{K}$ -- a gap that is necessarily positive when the achievement of viability is not just on the margin of feasibility. In fact, the difference between the maximum capital stock that could be achieved by some time T after the end of the reorganization period and the essential stock is a useful measure of how easy it would be, from the technological point of view, to achieve viability. The larger the difference, the more scope there would be for departures from the policy that would maximize the growth of capacity. Such departures might reflect deliberate, well-informed policy choices, or they might reflect an excessively optimistic view of the situation, resulting in the diversion of output to urgent but nonessential uses. They might also be the unintentional results of failure to find perfect solutions to the organizational problems of the economy. Economic policies during the reorganization period will be afflicted with and affected by imperfections in the apparatus that implements the policies and in the information and analysis on which decisions are based. Such imperfections need not spell failure of the reorganization effort, but they may do so if the problem posed by the

availability of resources and the technological conditions of production is sufficiently difficult.

Since decisionmakers will have much less than perfect knowledge of the future course of economic events and of the consequences of alternative policies, decisions will undoubtedly be influenced by a desire to hedge against unpleasant surprises. In particular, policy is likely to be influenced by concern with success in achieving viability even if it appears quite probable that viability will be achieved with no difficulty. But the better the potential results of a policy designed to maximize the excess of capacity over the value of essential capacity, the lower the risk involved in the departure from such a policy will be, and the smaller the influence that concern with a possible failure will have on the decisions made.[1]

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[1]The policy alternatives that will face decisionmakers in the reorganization period are discussed in more detail in Section VI.

IV. SPECIALIZED RESOURCES: THE INAPPROPRIATE COMPOSITION OF SURVIVING RESOURCES

The aggregative analysis just presented indicates that reorganization is a race between the depletion of inventory and the reconstruction of productive capacity. In spite of the drastically simplifying assumptions on which the simple model rests, it focuses attention on what are in fact the fundamental determinants of the technological feasibility of successful reorganization. But a model that shows only the fundamentals of a problem often suppresses details of critical importance from the point of view of prediction and policy analysis. Although it would be a simple matter to provide estimates of the parameters of the aggregative model, a quantitative analysis that ignored the nonhomogeneity of the stock of plant and equipment and of the labor force would be unlikely to provide reliable answers. The imperfect substitutability of resources within these broad categories would be of fundamental importance in the sort of economic situation that might follow a nuclear war.[1]

This section provides a detailed answer to the question of why the economic situation at the end of the survival period cannot be adequately described in terms of the number of man-hours of labor available, the value of the surviving plant and equipment at pre-attack prices, and the number of calories in the food inventory. A description at this level would probably seem inadequate to most people; although some of the reasons for the inadequacy are quite obvious, others are somewhat subtle. Furthermore, a detailed

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[1] This would not necessarily be true, however, if the problem being investigated related to feasible rates of <u>recuperation</u>. If reorganization is successfully accomplished, severe imbalances in the economy should be eliminated in the early years of the recuperation process. From that point on, an estimate of the feasible growth of the economy based on an aggregative production function should be about as relevant as similar estimates for the economy of today. Opinions differ on just how relevant that is, but calculations of this sort are generally thought to be useful.

examination of the aspects of reality not taken into account in the aggregative model may actually serve to support our assertion that these aspects are of second order importance compared with the ones that are taken into account.

An attempt to apply the aggregative model to determine the feasibility of reorganization under various circumstances would be likely to produce overoptimistic results. The composition of the aggregates in an actual postattack situation would not be ideally suited to the needs of the reorganizing economy; whereas, in the ordinary course of economic events, the composition of the labor and capital aggregates bears a more nearly ideal relationship to the composition of the output aggregate.[1] There are various reasons why this inappropriateness in the composition of the surviving resources would be likely to occur; and there would be various effects on the prospects for viability. The reasons given below are not strictly additive (in some cases the effects might even cancel each other out); but they are independent in the sense that any one of them could produce the indicated result in the absence of the others.

DISPROPORTIONATE DESTRUCTION

Since economic activity of various types is not spread evenly over the country, any given geographical pattern of destruction will in general affect some types of activity more than others. For example, petroleum refining or steel making capacity might suffer more severe destruction than other industries. Since these two industries provide essential inputs to other economic activities, there would be a tendency for output in other activities to be limited by the availability of steel or petroleum inputs, rather than by the availability of capacity.

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[1]And, of course, the estimated relationships between inputs and outputs on which the analysis would be based would have to be derived from observations on the "ordinary course of economic events."

A similar, and probably more serious, possibility exists with respect to the skill distribution of the surviving labor force. Persons with certain types of skills and experience, particularly persons with exceptional managerial abilities, tend to be highly concentrated in a few of the largest metropolitan areas. A war in which these areas were destroyed would, in the absence of an ambitious shelter program, leave the surviving economy with a severe shortage of these skills. Also, a war resulting in the destruction of a large part of the capacity in a particular industry would be likely to kill a great number of the people who have the skills and knowledge required to rebuild that industry.

Because a severe bottleneck is likely to reduce the economy's capabilities by a greater amount than would the same total destruction spread over many types of activity, the creation of such bottlenecks may be an objective of the enemy's targeting strategy. This objective was fundamental to U.S. strategic bombing strategy in World War II. The incentives for attempting "bottleneck" attacks will, however, be much less in a possible future war than they were in World War II, since attacks on industry will have little, if any, effect on the outcome of the war. An attack on industry _per se_ is unlikely so long as the attacker has alternative courses of action available that _would_ materially affect the outcome of the war.[1]

It is conceivable, however, that late in the war it might appear to the attacker that the war was going to end inconclusively and that the reduction of our economic recovery potential (and consequently our future power) was the highest priority use for remaining strategic capabilities. But in such a situation, the remaining capabilities might not be large enough to make a bottleneck attack an attractive

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[1]Of course, some destruction of productive capacity would occur as a result either of strikes at strategic forces located near cities, or as a result of city strikes. However, bottlenecks produced accidentally are unlikely to be as severe as those that would result from a deliberate effort in that direction.

option. The creation of a severe bottleneck would generally require that some weapons be assigned to targets that would otherwise be of no importance, because a significant fraction of an industry's capacity is likely to be relatively isolated from other economic resources. Unless the number of weapons available is large enough to make it quite certain that the bottleneck attack will succeed, a more general type of "counter-value" attack[1] might look more attractive to enemy planners.

It is possible to set forth a strategic doctrine under which attacks on resources essential to reorganization and recuperation would be an attractive option, particularly if such target systems were well separated from the population. The argument might be: Given the probable size of the strategic forces of the adversaries, a thermonuclear war in which any substantial fraction of those forces are spent on population targets amounts to mutual suicide; therefore, the first-priority strategic objective is to coerce the enemy into terminating the war on relatively favorable terms to us. It is not likely to be possible to destroy the enemy's capability to inflict a level of damage on us that would threaten our national survival, particularly if we conduct the war in a manner consistent with our first-priority objective; therefore, it is unlikely that we can coerce the enemy into unconditional surrender. A realistic second-priority objective is to make the postwar strategic situation as favorable as possible to us; this can be accomplished by increasing the enemy's postwar economic difficulties. Attacks on reorganization and recuperation targets not only further our second-priority objective, but, if such targets are separated from the population, they further our first-priority objective by both inflicting economic damage and sparing the

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[1]That is, an attack on some broad resource category that is highly valued by the United States -- the population, manufacturing capacity in general, heavy industry in general, and so on.

population, thus preserving his most powerful incentive to refrain from initiating an all-out exchange against population targets.[1]

CHANGED CAPITAL-LABOR RATIO

This is really a special case of disproportionate destruction -- of capital in relation to labor. It is argued below that disproportion might be in either direction, depending on civil defense preparations, the enemy's targeting strategy, and other factors. In any case, the composition of the capital stock, and the skill distribution of the labor force, will not be appropriate to the changed conditions. The nature of the resulting problem can be clarified by examining hypothetical situations in which the imbalance is extreme in one direction or the other. Suppose first that the nation's physical capital is left essentially intact but a large proportion of the population is killed, perhaps as a result of a very heavy but discriminating "counterforce" attack and negligible fallout protection. The resulting high ratio of capital to labor would make possible a high level of labor productivity, if only the capital embodied a very highly mechanized and "automated" production technology. In fact, however, the labor force would be inadequate to operate the equipment that actually existed, and only a part of the capital could be put to work. In an extreme case, the labor force might be so small as to make it impossible to run all essential industries simultaneously at the minimum technologically feasible level, and the paradoxical result might be to force the population to support itself by subsistence agriculture.

At the opposite extreme, if excellent blast and fallout shelter were available for the entire population and a war occurred involving extensive city attacks, only a fraction of the nation's plant and equipment would survive. Viability might be readily achieved in

[1]This argument does not seem sufficiently compelling to warrant assigning it very much weight in judging the prospects for reorganization.

this case if the surviving capital were of a sort that would permit most of the labor force to get to work immediately and effectively to produce the necessities of life, which might mean that the surviving capital should consist of hoes, shovels, axes, spinning wheels, and so on; but if it consisted of a few highly automated automobile and chemical plants, viability might be impossible to achieve.[1]

The general point illustrated by these extreme examples is that, for any aggregate ratio between capital and labor, there is a corresponding optimal composition of the capital stock and skill distribution of the labor force. When the aggregate balance is suddenly changed and the composition is not adjusted correspondingly, the economy is less productive than consideration of the aggregates would suggest.

CHANGED SCALE

The optimal composition of the capital stock also depends on the total size of the economy. This dependence is the result of important indivisibilities or instances of "increasing returns" in the production technologies for some goods and services.[2] This subsection treats some of the implications for reorganization of increasing returns in individual industrial plants. Other significant

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[1]If the surviving inventory of necessities were sufficiently large, a partial conversion of the surviving capital into a more useful form might be possible. But if reorganization were otherwise on the borderline of feasibility, the inappropriateness of the surviving capital would make the difference. Here, as elsewhere, many of the statements made about the appropriateness of the composition of the capital stock can readily be converted into corresponding statements about the skill distribution in the labor force.

[2]The concern here is strictly with instances of technological increasing returns. In any given industry, costs may be lower at higher output levels because some inputs become cheaper, that is, for reasons that have to do with the conditions of supply of some productive factors. But these reasons are typically instances of technological increasing returns in the industry supplying the inputs, and do not have to be considered separately.

cases of increasing returns occur in the case of "social overhead capital" -- roads, water and sanitation systems, and so on. The issues raised in these cases are intimately involved with the question of the geographical distribution of surviving capital, and are discussed later in this section and in Section VII.

Increasing returns and indivisibilities in production processes at the level of the individual plant result in inappropriate composition of the surviving capital stock in two related ways.[1] First, plants designed to minimize costs at preattack levels of output may make inefficient use of labor and materials at postattack levels. Therefore, the cost of producing given output items may be higher than it would be if the surviving capacity had been designed with the postattack situation in mind. Second, preattack capacity may not be well suited for producing the most efficient postattack output mix. Composition of the surviving capacity will thus be inappropriate, not just as a result of disproportionate destruction of different types, but because the preattack composition was itself inappropriate for the postattack situation. In fact, some types of capacity that would be desirable postattack may not exist at all preattack, so it would be impossible for any pattern of destruction to result in an ideal composition of surviving capacity.[2]

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[1]In the interests of clarity, the question throughout Section IV should be reiterated at this point: Given the preattack prices of various capital goods (or of providing workers with various skills), why might the actual postattack capital stock differ from a capital stock of ideal composition from the point of view of achieving viability and having the same value at preattack prices?

[2]Except in the extreme case where certain types of capacity do not exist preattack in the amounts that would be ideal postattack, it would be possible for the disproportionate destruction to cancel out the inappropriateness of the preattack capital stock; differential survival of capacity or different types of capacity might "correct" the preattack composition.

The first consideration -- the effect on the cost of producing given output items -- is of importance only if, in some industries or product lines, the postattack demand[1] is small relative to the scale[2] of the smallest surviving plant.[3] Obviously, if demand equals or exceeds the total surviving capacity, the behavior of costs at below capacity levels of operation is of no significance. Not so obviously, if demand is less than the total surviving capacity, but still large relative to the smallest surviving plant, the reduction in output will not affect costs; the reduction can be accomplished by shutting down some plants rather than by operating them all at an uneconomically low level. Only as the level of demand approaches[4] the scale of the smallest surviving plant does the behavior of costs at less than capacity operation of the individual plant become a relevant consideration.

Even if, for technological reasons, the minimum efficient scale of plant is quite large, it may still be that average variable costs of production -- labor and materials costs -- do not increase when output is well below this minimum efficient scale. The cost considerations that make the minimum efficient scale of plant quite large might consist exclusively of influences on fixed costs; for example, the cost of a single unit of an important item of equipment. From the reorganization point of view, very high average total costs

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[1]To be precise, the quantity demanded at a price equal to average total costs at the minimum cost output level.

[2]The output level at which average total costs are a minimum.

[3]It is assumed for simplicity that the cost situation is the same for all producers, and that the size distribution of plants was in equilibrium preattack. Thus, if there is a unique plant size that has minimum costs, all surviving plants will be of that size. If costs are independent of plant size over some range, there may be surviving plants of various sizes.

[4]Depending on the exact position of the demand curve, and the size distribution of plants, costs may or may not be significantly higher than the minimum when demand is, say, two or three times the scale of the smallest surviving plant (there is a "scalloped" industry supply curve).

at the postattack output levels do not make this case any different from the case where no increasing returns phenomena exist but postattack demand is low relative to surviving capacity. The prospects for reorganization would, of course, be brighter if the surviving capital had happened to be nonredundant capacity in another industry. But given the fact that more capacity survives in the industry than is needed, it does not matter whether this capacity is in one plant or in several, so long as variable costs are the same in both cases. It may happen that average variable costs are affected by underutilization of capacity. The most obvious and important way in which this can occur is that there may be no efficient way of dividing up the various tasks in the productive process among a small number of workers. This is more likely when various tasks require specialized skills or training, for it will be wasteful or impossible to shift a single worker from one task to another, and the only alternative is to have a larger, but underemployed, work force. At a price that will cover these higher costs, the quantity demanded will be less, so costs will be increased further. It is conceivable that the best course of action might turn out to be no production at all.

The second effect of increasing returns phenomena is the inappropriateness of the preattack composition of capacity. The tremendous profusion of highly specialized, minutely differentiated products characteristic of the American economy today is economically efficient only because the market for each one is sufficiently large to make possible an efficient scale of output. The postattack economy, with a smaller total output, would ideally produce a smaller variety of products. Product specifications would be more standardized; purchasers who formerly acquired a product variant tailored precisely to their needs would settle for a standard item at a lower price.[1] However, the surviving capital stock will not be ideally

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[1]Increased standardization is sometimes referred to as "rationalization of production." It should be mentioned that the profusion of distinguishable products in the economy of today is in part the result of product differentiation undertaken in an effort to strengthen the monopoly power of the firm, and to that extent it is not economically desirable.

suited for the smaller size of the economy; it will be overspecialized. Some reduction in the range of products will occur when demand is zero at prices that will cover costs; so the inappropriateness of the surviving stock will be revealed in idle capacity. In other cases, it will not be possible to forego production of specialized items. Spare parts for surviving machinery must be produced in essentially their full preattack variety, at least for types of machinery that are in short supply;[1] or capacity for producing a more standardized item may be inadequate. In these cases, the effects of overspecialization will be increased costs associated with underutilization of capacity and short production runs.

Another effect of the overspecialization of preattack capacity is to magnify the problem of disproportionate destruction. The greater the number of specialized types of industrial capacity that have to be distinguished -- because surviving capacity of one type could not meet the full range of needs formerly met by capacity of another type -- the more likely it is that a given amount of destruction will completely eliminate all the capacity in some categories. For example, the greater the extent to which individual facilities producing machinery are specialized in the production of capital equipment for a specific industry -- textile machinery, petroleum refining equipment, and so on -- the more likely it is that little or no capacity will survive to produce new equipment for some industry. Even rather minor cases of product differentiation among companies vigorously competing with each other preattack may cause trouble to the postattack economy. For example, some time would surely be lost and costs incurred if spare parts for surviving electronic computers of all makes had to be produced in the plants of a single company.

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[1] For types of machinery surviving in amounts in excess of requirements, the solution to the parts problem may be found in "cannibalization," that is, dismantling some machines to obtain parts for others.

INAPPROPRIATE GEOGRAPHICAL DISTRIBUTION

Another perspective on the appropriateness of the composition of surviving resources may be obtained by considering the geographical distribution of economic activity. Since the national economy may be viewed as a system of regional economies that trade with each other, the foregoing analysis of the sources of inappropriateness can be applied to the regional economies separately. For example, disproportionate destruction might affect each of the regional economies even if the national totals revealed no imbalances. If the great dams of the West were destroyed, the West would be relatively lacking in water and electric power while the East might have an abundance of these things. A war in which cities were attacked would probably produce a relative labor shortage in the rural-agricultural areas (assuming inadequate fallout protection) and a relative capital shortage in the urban-industrial economy.[1] Similarly, a large surviving capacity in the nation as a whole in relation to the size of individual plants in a particular industry would not necessarily permit avoidance of the increased costs associated with underutilization of individual plants. Transportation costs might be so high as to rule out the possibility of shutting down some plants and operating the others at efficient output levels.

The quantitative importance of any given instance of geographic maldistribution of surviving resources depends on the transportation costs involved in eliminating or overcoming that maldistribution. As those costs approach zero, the economic impact of the maldistribution disappears; therefore, its significance will tend to be greatest

[1]It is worth noting that a highly uneven geographical distribution of the attack might well result in the most favorable distribution of surviving capacity, since large areas would be untouched and could serve as centers of reorganization. This is the image conveyed by Herman Kahn's "A country - B country" distinction. On Thermonuclear War, Princeton University Press, Princeton, 1960.

when the transportation costs for the resources involved are high or infinite.[1]

The transportation system itself provides some of the most important instances of resources whose transportation costs are very high. If, as seems likely, the surviving railroad lines and highways do not constitute a network well suited to the needs of the postattack economy, it will obviously not be possible to remedy the situation by moving the highways and railroads.[2] Instead, the economy will have to carry the burden of higher transportation costs associated with inefficient routings and congestion of those links on which demands are heaviest.

Extensive city attacks would produce the most severe damage to railroads and highways, since the destruction of a single city is likely to break several of the links connecting other cities. In the case of railroads, the destruction of classification yards incidental to city attacks is also likely to cause problems. Other important vulnerabilities of the transportation system are at major rivers, mountain ranges, and other natural barriers, because there are usually few alternative ways of crossing a major barrier. A similar situation exists in communications industries. The usefulness of a surviving link depends on where it is. The same is true of electric power distribution, and, at a more localized level, of water supply and sanitation systems.

For some major types of economic activity, for example, the steel industry, transportation costs for one or more raw materials are the main influence determining the geographical distribution of the industry. It may happen that the surviving processing capacity

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[1]In some cases where the costs of eliminating the maldistribution would be high or infinite, the costs of overcoming it by making some other adaptation may be relatively small. Thus, maldistribution will only tend to be greatest when the resources in question have a high transportation cost.

[2]This statement may be too sweeping. It is possible to pull up lengths of railroad tracks, ties and all, and move them somewhere else. This could turn out to be an efficient way of patching up the railroad network.

is not located in the same regions as the surviving sources of raw material; a steel plant may survive in an area where iron ore or coal is not available, while in another region the raw materials are available but the steel plant is not. The transporation costs involved in making the various pieces of surviving capacity function as a system may then be very high indeed, perhaps too high to make the effort worth while. However, the chances are not too great that the pattern of destruction would produce such a result. In general, processing facilities are considerably more likely to be destroyed than raw materials sources. Severe imbalances between intermediate product or component capacity and final product capacity are more probable, but in these cases the transportation costs inflicted by the maldistribution would be less significant.

The distribution of the labor force in relation to the surviving capital could well require some major shifts of population in the reorganizing economy. It has already been suggested that there might be a relative shortage of labor in agricultural regions; this would be intensified if severe petroleum shortages made it necessary to adopt less highly mechanized agricultural techniques. It could also happen that some of the most important of the surviving industrial plants would be in regions where a large percentage of the population had been killed. The task of moving labor to the regions where it is needed, and of supplying it with necessities when it is relocated, could be a major demand on the transportation system.

CHANGED COMPOSITION OF DEMAND

Suppose that the various facts of economic life that give rise to the four considerations discussed above did not hold. Suppose, for concreteness, that all industries are destroyed in the same proportion, that more capital is destroyed than labor but the capital stock is completely flexible in this respect, that there are no economies of scale, and that the geographic distribution of the surviving capacity is ideal. Nevertheless, the economy would not be

perfectly adapted to the task of reorganization. At the lower levels of per capita income resulting from the lower ratio of capital to labor, the composition of consumer demand would be different. Purchases of luxuries would be cut back more than purchases of necessities. Also, it seems reasonable to suppose that a higher rate of economic growth would be more desirable than was the case preattack; there would be a general shift of demand from consumption goods to capital goods and a shift among the different types of capital goods.[1] Finally, the character or relative size of government expenditures would be very likely to change. For all of these reasons, the composition of demand would be different in the reorganizing economy than it was preattack. The capital stock, which by assumption would retain its preattack composition, would therefore not be entirely appropriate to the economy's needs. The prospects for reorganization and recuperation would be brighter if destruction were not equiproportional, but rather followed a pattern that left the surviving stock in conformity with the changed pattern of demand.

The most serious aspect of the inappropriateness in the capital stock resulting from changed composition of demand would be a comparative shortage of capacity for producing food and other necessities. Surviving capacity for producing consumer durables will be of relatively little use in meeting needs for food and water, shelter and heat, medicines and medical care facilities. Even within the necessities category, there may be significant maladaptations of the surviving capacity. For example, it could easily be shown that per capita expenditures on food in the economy today are many times what would be needed to keep the population healthy if the average diet were much simpler and arrangements for distribution were austere. But the present capacity is not adapted to simple diets and austere distribution; it is adapted to a diet heavy on meats, fruit, and

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[1] This would clearly be the case in the reorganization period, since growth would be required in order to restore the economy to viability. It would probably also be true in the sense that, at the end of the reorganization period, the composition of the capital stock desired would be appropriate to a fairly rapid recuperation rate.

vegetables, and to a distribution system heavy on supermarkets, individual packaging of meats and vegetables, and frozen, "ready-mix," and "brown 'n serve" foods. Of course, adaptations to post-attack conditions could be made, but they would not be costless. Thus, a calculation that measured the excess in our food production and distribution system by the difference between present-day food expenditures and the expenditures that would be necessary to maintain the health of the population would not provide an accurate indication of the amount of capacity that could be lost without endangering the viability of the system.

To the extent that the composition of the capital stock in the capital goods sector reflects the composition of output in the consumption goods industry, the maladaptations noted above in the consumption goods sector will be compounded by corresponding maladaptations in the capital goods sector. The capital goods sector will not be well adapted to producing the output that would remedy the situation in the consumption goods sector. Finally, the capital goods sector would be less than ideally adapted to the task of providing materials and parts needed in the repair of the large amounts of partially damaged capacity that would certainly exist.

The observation that the various possible sources of inappropriateness in the composition of surviving capacity are not necessarily additive in their effects should be reiterated. Disproportionate destruction in various industries may leave the economy well adapted to the changed output mix dictated by other considerations, or it may intensify shortages of particular types of capacity made severe by the other considerations. A detailed analysis of patterns of destruction and of postattack demand would have to be made to determine the degree of inappropriateness that might exist, but such a determination would represent only a first step in assessing the implications of the imperfect substitutability of different resources for the success of the reorganization effort.

V. SPECIALIZED RESOURCES: THE FEASIBILITY OF OVERCOMING SPECIFIC SCARCITIES

If calculations within the framework of an aggregative model, such as that presented in Section III, suggested that reorganization was just on the margin of technological feasibility, then even a minor degree of inappropriate composition of the aggregates would presumably spell failure. If the aggregative calculations suggested that a considerable margin of safety was available -- if the food stock appeared more than adequate to permit the capital stock to be brought to its required level -- then the question would remain whether some margin still existed after allowances had been made for the inappropriate composition of the aggregates. The answer depends not only on the extent of the inappropriateness, but also on the extent to which the economy could adapt to or eliminate that inappropriateness, which in turn depends on the substitutability of resources in production and use, on the structure of the technology, on the extent of indivisibilities in capital goods, and on the extent to which new technology may be developed in response to the problems of the reorganization period.

SUBSTITUTABILITY

It is clear that if the standard of comparison is a hypothetical situation in which all production and consumption is governed by fixed coefficients,[1] the extent of the substitution possibilities available in the American economy is enormous. To begin with, there are innumerable possibilities for substituting products in final use. For example, there are many possible diets that are nutritionally adequate, and some of them make much smaller demands on certain agricultural inputs than others. A second dimension of substitution is at the level of basic materials and energy sources. Steel and aluminum

[1]That is, every production process requires inputs in certain fixed proportions, so that there is no possibility whatever of substituting one input for another; similarly, consumers do not vary the mix of goods they consume in response to relative prices.

are close substitutes over an important range of applications and, of course, different types of steel overlap in their range of usefulness. Scrap can be used in place of new ore. Electric power is producible by hydroelectric plants or by thermal plants burning coal or fuel oil. Finally, in production processes, different types of capital equipment can be substituted for one another. Perhaps more important, machinery of a given type in one industry can perform the tasks formerly done by machinery of the same type in another. Labor can be substituted for capital in multi-shift operations in industries where this had not been standard practice. Maintenance and repair can substitute for new equipment. Spare parts can be supplied by cannibalization instead of by new production. In agriculture, fertilizer, land, labor, and tractors and tractor fuel can all be substituted for one another to some degree. In transportation, the different modes are substitutable for each other to a great extent. The list is virtually endless.

In almost all of these cases the extent to which the substitution can be carried out is limited. There is a range of applications in which steel or aluminum would do equally well, so that the choice between them depends on their prices and the costs of working them. There are applications where one could serve in place of the other if necessary, that is, if the price incentives were very strong. And, of course, there are ranges where it would be difficult indeed to replace one with the other. This general truth about substitution possibilities is, of course, reflected in the conventional shape of the production isoquant of economic theory. Figure 2 illustrates the situation that might arise with respect to the requirements for steel and aluminum in the reorganization process, all other considerations taken as given. There is a range pp' where it is essentially a matter of indifference whether there is one ton more of steel and less of aluminum or the other way around. But there are also some minimum requirements for both materials: if less than s tons of steel (or a tons of aluminum) were available, no amount of the other material could compensate for this shortage.

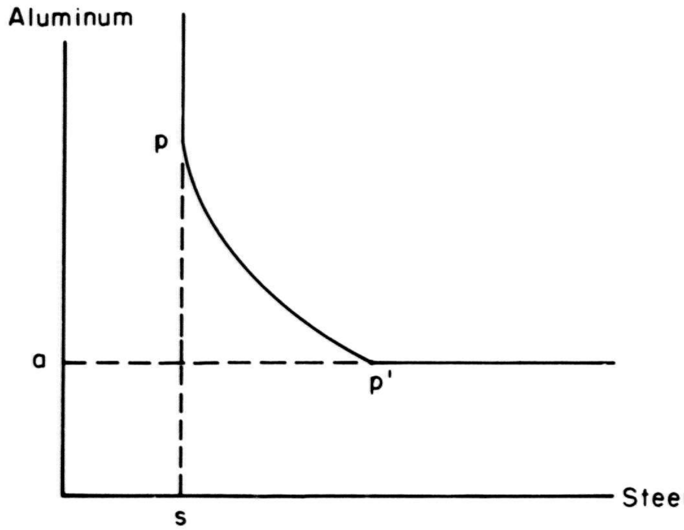

Fig. 2 — Requirements for steel and aluminum in the reorganization process (illustrative)

The enormous destructive potential of thermonuclear weapons forces consideration of the possibility that destruction of particular resources, or even of broad classes of resources, might be so extreme that the range of relatively perfect substitutability would be left far behind. There are many ways that use of electric power plants, petroleum refineries, railroad rolling stock, and agricultural land could be economized; but unless large scale imports were possible, viability could probably not be achieved if the nation's endowment of these resources were orders of magnitude below the present amount in per capita terms.[1] Electrical machinery and electric lights cannot be operated with anything but electricity; supplies of natural gasoline are not adequate to provide the fuel for trucks and tractors; the railroads are by far the most efficient way to move bulky commodities; yields per acre of land cannot be raised indefinitely. If, under plausible assumptions about the course of the war, it appears that very severe destruction of these resources might occur, then only a detailed quantitative study of the particular problem can answer the question of whether the feasible economies and substitutions will make reorganization possible or not. It is beyond the scope of this Memorandum to provide such studies, but some of the available evidence is summarized in Section VII.

The limits on the substitution possibilities available in the reorganization period are considerably more severe than is the case in the long run in a functioning economy. To a considerable extent, the preattack relative prices of different materials, types of capital equipment, and so on, are reflected in the composition of the capital stock. Consequently, some substitutions can be carried out only when the composition of the capital stock is altered through new investment. Consider, for example, the possibilities of substituting coal for oil and natural gas. Historical experience shows that coal could play a

[1]In the case of petroleum refineries and agricultural land, this statement would have to be qualified if very large stockpiles of the relevant products were available.

much larger role than it now does in providing fuel for the railroads, for electric power generation, and for home heating. But coal cannot be burned in diesel locomotives, in fuel oil-fired boilers in power plants, or in natural gas furnaces in homes. Consequently, it is very doubtful whether an expansion in the use of coal in these areas could be timely enough to make more oil and gas available to power tractors, airplanes, and motor vehicles in, say, the second year after the war.

The available comprehensive descriptions of the technological conditions of production in the American economy do not afford a sufficiently detailed view of the possibilities to permit a definitive analysis of the ultimate implications of any particular pattern of resource availabilities. It is often possible, however, to demonstrate that specific scarcities could be alleviated, assuming the availability of certain other resources, simply by referring to a known substitution or production possibility. But it is generally quite difficult to demonstrate that a severe scarcity of a particular resource would pose an insuperable obstacle to the achievement of viability, for knowledge of the technological possibilities is never complete. In the spectrum of situations considered, from those that are very favorable to the achievement of viability to those that appear to be much less favorable, the conclusions range from "success likely" to "success highly uncertain." "Success impossible" is rarely warranted.

TECHNOLOGICAL STRUCTURE

Certain considerations affecting the feasibility of reorganization are, in a formal sense, simply a special aspect of the problems raised by imperfect substitutability of resources for one another. But these considerations derive from an implication that is sometimes overlooked. Some economic resources are essential, or nearly essential, direct or indirect inputs in their own production. It will be argued that this is a fundamental determinant of the vulnerability of the economy to a failure in reorganization, and a fundamental

reason why the extent of the economic setback that a given pattern of destruction would involve cannot be reliably measured by the value of the destroyed resources at preattack prices.

First, some basic concepts must be introduced. The "closed model" view of production is adopted; that is, households are considered to be one of the industries of the economy, producing labor as an output and consuming essential consumption goods as inputs.

A resource (or service), A, is considered dependent on a resource (or service), B, if the production of a unit of A is possible only if some nonnegligible amount of B has been used as an input in some production process (which may, in the simplest case, be the process producing A) at an earlier time. For example, if B is a material out of which A is made, A is dependent on B. Also, if A is dependent on B, and B is labor, then it is clear that A is also dependent on food; for without a prior input of food into the households industry, the labor used to produce A could not exist. If A is dependent on itself, then it is self dependent.

The general proposition that is advanced is that some self dependent industries are likely to be of critical importance in the reorganization process in relation to industries that are not self dependent, and that peacetime valuations of the outputs of industries of the two types do not reflect this difference. To suggest the nature of the mechanisms that produce these results, the following very hypothetical example is presented. Suppose a disaster occurs that destroys all of the plants in which TV sets are produced and kills 90 per cent of the beef cattle and leaves everything else unharmed. Suppose that success in recuperation is defined as restoring production of steaks and TV sets to predisaster levels in two years, while, of course, continuing to meet the subsistence needs of the population. Also assume, for the moment, that neither cattle nor equipment for producing TV sets can be imported. Now it is quite obvious that there will be no difficulty in meeting the TV set requirement; the value of the capacity lost is trivial compared with

the ability of the economy to build new capacity. It is equally obvious that it is not possible to meet the steak requirement, in spite of the fact that the value of the loss, at predisaster prices, is also small relative to the productive powers of the economy, and in spite of the fact that 10 per cent of the cattle survive. The difference between the two cases reflects the fact that cattle production is self dependent, whereas capacity for producing TV sets is not. Suppose there is now a possibility of imports, first of TV set capacity and then of cattle, and ask how high the prices asked for these commodities would have to be before trade would not be worth while, if the assumed requirements are taken seriously as national goals. For TV set equipment, the highest price is not much above the predisaster price for the equipment, since the nation can produce the equipment itself with only a moderate increase in costs. For the cattle, however, the fact that imports are essential if the requirement is to be met implies that the purchase would be worth while even if the price were so high that it would be necessary to spend everything the economy had left over after meeting the TV set requirement and the subsistence requirement. Thus the price ratio between cattle and TV set equipment that measures their true relative scarcity in this situation differs by a tremendous amount from the predisaster prices.

Examples of self dependence, in the absolute sense in which it has been defined here, are quite rare outside of the realm of technological relationships that are governed by biological facts. There are, however, a large number of situations in which the quantitative economic significance of the distinction between processes that use A in the production of A and alternative processes that require no A as an input approaches, for practical purposes, the infinite difference in feasibility that exists between cattle producing processes that use cattle and those that do not. The first electrical generator ever made was not constructed under electric lights with the assistance of power tools, and presumably generators can still be made the

way the first one was. But this does not have a great deal of bearing on the probable consequences to the economy if every generator now in existence suddenly disappeared. The fact that the original capacity in each of our basic industries must have been constructed without the assistance of previously existing capacity in that industry refutes the assertion that they are self dependent according to definition. But, as a practical matter, the total destruction of any one of these industries would produce economic effects qualitatively different from the effects of destruction of capacity of equal value in the consumer durables or aircraft industries, for reasons that have to do with the usefulness of generators, steel, and so on in producing more generators, steel, and so on.

The above definition of dependence (as opposed to self dependence) suffers not only from the fact that the production of A is often just barely possible without an input of B, but also from the fact that the existence of a relation of dependence often depends on the precise definition of the resources involved. For example, labor is dependent on food (measured in calories of food energy), but it is not dependent on any single food item. Steel is certainly dependent on the element iron; it is not, however, dependent on iron ore.

The concepts of dependence and self dependence will be used quite loosely in the subsequent discussion. One of these relations will be said to hold even in cases where it holds only approximately. The main interest, at this point, is in obtaining whatever insights into the viability problem these terms suggest, not in manipulating them with mathematical precision. The formulation of a complete set of precise definitions of various degrees and types of dependence among resources (and perhaps among sets of resources and functions on sets of resources) should await the completion of a preliminary exploration of the territory to which intuitions derived from these terms may lead.[1]

[1] In Appendix B, a start is made on the task of formulating precise definitions within the framework of the theory of production.

The basic implication of the self dependence of a resource is that there is a limit on the rate at which the supply of the resource can be expanded in the long run that is independent of the supplies of all other resources. In the case of cattle, the rate at which the supply expands is affected by the availability of other resources (for example, abundance of other resources may mean it is not necessary to slaughter cattle for food, all cattle can be provided with the best feed, veterinary services, and so on) but it cannot be increased above biologically determined limits.[1] By contrast, there is presumably no limit to the rate at which TV set capacity can be increased, provided that the appropriate composition of resources is available. The significance of the existence of a limit depends, of course, on whether the limit is high or low. The lower the limit, the wider the range of situations in which the resource is the effective constraint on its own rate of expansion. However, even a resource for which the limit is very high (as is presumably the case with generators) will be an effective constraint on its own rate of expansion if the initial imbalance in supply between that resource and all others is sufficiently severe (as would be the case if all generators, and nothing else, were destroyed).

The self dependence of some resources suggests that the familiar term "bottleneck" may obscure important distinctions among economic situations. As the term is commonly used, a bottleneck exists whenever a sudden shift in supply or demand results in a short run equilibrium price far above the long run equilibrium price (relative to other resources). Since no resource is in completely elastic short run supply, such a situation can arise for any resource, given sufficiently drastic supply and demand shifts. The "bottleneck" metaphor suggests that the resources to remedy the situation do exist; the problem is to bring those resources to bear on the scarcity (that is, to "break the bottleneck").

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[1]A few years ago, this fact served as the basis for a criticism of the Soviet Union's projections of meat and dairy products output. Khrushchev was asked whether a way had been discovered to assure that every cow would bear twins.

The cases in which the scarcity itself constrains the effort to eliminate it are not distinguished from the cases in which the availability of other resources and production leadtimes are the only constraining factors. The term "vicious circle" provides a more suggestive characterization of self dependence scarcities than does the more general term "bottleneck." The search for the means to eliminate the relative scarcity of a particular resource always comes back, sooner or later, to the fact that the resource itself is in short supply.

Some of the implications of self dependence for viability are revealed in the following hypothetical situation: an economy is initially nonviable and at least a certain minimum output of both resource A and resource B must be produced within a certain time period if the economy is to achieve viability. Resource A is self dependent but resource B is not. Given the amounts of all other resources at the start of the reorganization period, what combinations of amounts of resources A and B surviving are consistent with the achievement of viability? The answer is likely to have the qualitative properties displayed in Fig. 3.[1] All combinations on or to the right of the curve are consistent with success. Because resource A is self dependent, some positive amount $\bar{A}$ must survive if the requirement for a certain output in the course of the reorganization period is to be met. Thus the additional amount of B that would have to survive in order to compensate for the loss of another unit of A becomes arbitrarily large as the survival of A declines toward $\bar{A}$.

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[1]That is, these results will hold for a wide range of assumptions about the availability of surviving resources. The main condition that must be satisfied is that the inventory of products embodying resource A (for example, the inventory of the product, if A is a type of capacity) shall not be of such a size and composition as to meet the minimum requirement for A. For example, if A is petroleum refining capacity, the condition is that the stocks of petroleum surviving not be so large as to meet essential requirements for petroleum (including the petroleum required in the various industries that provide inputs for the construction of petroleum refineries) by themselves.

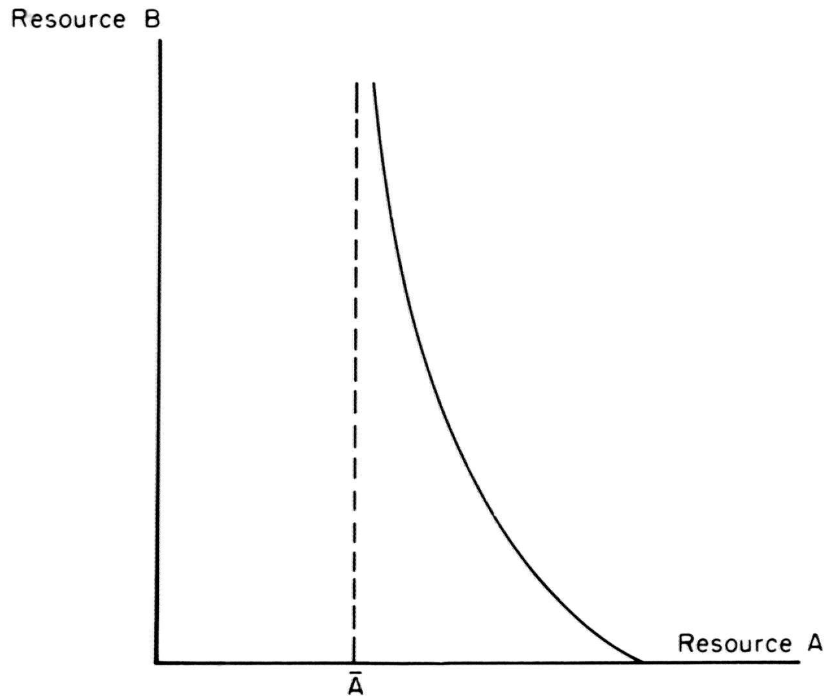

Fig. 3 — Combinations of resource survival consistent with the achievement of viability (illustrative)

On the other hand, B is not self dependent. Therefore, assuming that A can be applied, directly or indirectly,[1] to produce B, and assuming the period of time in question is longer than the leadtime of the production processes by which this is accomplished, a finite level of survival of A can fully compensate for the total loss of B.

The slope of the curve at any point (or rather, the absolute value of the slope) defines the ratio of what may be called the "viability prices" of A and B when the two resources survive in the amounts represented by that point. On this interpretation, the conclusions above can be restated as follows: As survival of the self dependent resource tends toward some positive lower limit, the viability price ratio P_A/P_B tends to infinity. But the ratio does not tend to zero as the survival of the non-self-dependent resource approaches zero. In fact, if the production processes by which the last increment of A replaces the last decrement of B were in use preattack, the viability price ratio equals the preattack price ratio when no B survives, and is higher otherwise. This is the basis for the earlier statement to the effect that there may be a general tendency for preattack price ratios to understate the importance of self dependent resources from the point of view of viability.

The Subsistence Loop

Certain instances of self dependence in the technological structure of the economy seem likely to be particularly important in determining the feasibility of successful reorganization after massive destruction. When the fixed requirement is negligible, the problem of achieving viability reduces to the problem of restoring the economy to a state in which it can support the population, and maintain the capital stock essential to the support of the population, out of current output. Because labor is necessary to produce means of

[1] A might be applied indirectly to the production of B by producing C which could be used as an input to B, or by substituting for D in the production of C, thus freeing D to produce B, or by still more complicated substitution chains.

subsistence, and the production of means of subsistence is necessary to the continued supply of labor, labor and subsistence goods are mutually dependent. And, as a result of this mutual dependence, labor is self dependent, and so is each subsistence good and each good on which a subsistence good is dependent. A set of industries that are all self dependent and mutually dependent are referred to as a loop, in this particular case, the subsistence loop.[1]

When an economy is just on the margin of viability, as it is in some underdeveloped countries and as it was in Germany for a period after World War II, the vicious circle aspect of the self dependence of industries in the subsistence loop becomes apparent. In fact, reference is sometimes made to the "vicious circle of poverty." Because the diet is inadequate, labor is unproductive and food output is low; and because food output is low, the diet is inadequate. In underdeveloped countries, a situation of this sort is likely to be locally stable; in the absence of major shocks,[2] it is likely to perpetuate itself. In an industrialized economy in the aftermath of a war there may be a period when it appears that the situation is stable, but it is likely to turn out to be unstable. That is, the situation may improve or deteriorate at a barely perceptible rate for a time, but there will eventually be an accelerated movement in one direction or the other. One of the several reasons for this difference between the two cases is that a war-ravaged economy is likely to have a good deal of intact capital standing idle or underutilized for want of complementary facilities. A small amount of new investment may produce a dramatic improvement in the situation. Only a small difference in the economy's capabilities separates this case from one in which the economy is gradually consuming the surviving capital by failing to make good depreciation, and thus following the path to disaster.

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[1] In a technology of the Leontief (input-output) type, a set of industries is a loop if and only if the corresponding minor of the inverse matrix is strictly positive. In an indecomposable Leontief technology, every subset of industry is a loop.

[2] On the one hand, a major natural disaster; on the other, large-scale capital imports.

It should be noted that the vicious circle relation between subsistence goods industries and the labor supply might appear for reasons other than a physical weakening of the labor force resulting from an inadequate diet. Particularly in economies where the population is accustomed to a standard of living far above physiological subsistence levels, various forms of social unrest may result from levels of consumption that are low but not seriously inadequate in physiological terms. If a significant fraction of the labor force seeks to improve its position by strikes and demonstrations, output is likely to decline and a cumulative deterioration in the situation may occur.[1]

To sum up, the obvious fact that the industries essential to the support of the population are of greater importance from the viability point of view than industries producing inessential consumption goods (or meeting nonconsumption demands not included in the fixed requirement) can be regarded as an instance of the general tendency for self dependent resources to be of greater importance than those that are not self dependent. The appearance of a vicious circle relation between the supply of labor and the supply of subsistence goods is the danger signal that indicates the economy is close to the point where it may fall into a cumulative downward spiral.

The Capacity Expansion Loop

Another important example of self dependence in the economy's technological structure is the self dependence of the industries that produce plant and equipment, or provide essential inputs to these industries, or inputs to the industries that provide inputs, and so on. Clearly, the subsistence loop is contained in this set of industries, since the industries that produce plant and equipment need labor as an input, and, in addition, some industries in the subsistence loop need plant and equipment. For present purposes, only those relations of dependence and self dependence in this set

[1]This matter is discussed at greater length in Section VI.

of industries will be considered that would still exist even if labor is disregarded as a necessary input. Such relations clearly exist; generators, steel, machine tools, and petroleum have been cited as examples of self dependence, and in none of these cases is it necessary to appeal to the usefulness of these things for producing subsistence goods in order to establish the point. These industries are also mutually dependent (for example, all of these industries depend on transportation and transportation depends on petroleum), and therefore constitute a loop. More precisely, the set of industries that (a) are necessary to capacity expansion in some industry, (b) would remain so even if labor were disregarded as a necessary input in all processes, (c) are mutually dependent and self dependent, and (d) would remain so even if labor is disregarded as a necessary input in all processes, is called the capacity expansion loop. The effect of condition (b) is to exclude households, food processing, apparel, and so on from the loop. The effect of (d) is to exclude farm equipment, and the like, which are necessary to capacity expansion in agriculture, but not self dependent if labor is disregarded.[1]

The self dependence of the industries in the capacity expansion loop raises the possibility that severe destruction may give rise to a vicious circle restraining the rebuilding of capacity, even if stocks of subsistence goods and the supply of labor are ample. Breaking out of the circle might require that capacity be built by methods drastically more costly and time consuming than the methods used to create new capacity under normal conditions. No such possibility exists outside of the capacity expansion loop. Among those industries in the subsistence loop but not in the capacity expansion loop, the assumption of ample stocks of subsistence goods and ample labor precludes the existence of vicious circle. Among other industries -- for example, those producing inessential consumption goods -- it is even more obvious that a shortage of capacity in those

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[1]Formally, "disregarding" an input is essentially the same thing as considering it a free good.

industries does not constrain the effort to expand capacity there or elsewhere.

As has been stressed before, self dependence is ultimately a quantitative matter. If the steel required, directly or indirectly, to build a steel plant were equal to one year's output of the plant, then capacity could double every year if other resources were available and no other demands for steel were satisfied. If the steel required were only a tenth of a year's output, capacity could be increased ten fold every year. In an actual postattack situation, the demands of subsistence and the fixed requirement would have to be met, and, in addition, not all of the other resources would be in abundant supply. Severe destruction in several industries in the capacity expansion loop would lead to a much slower growth of capacity in all industries than the extent of self dependence in any single industry would suggest.

The general tendency for preattack prices to understate the importance of self dependent industries for viability probably applies in the case of the industries of the capacity expansion loop. However, the relative viability prices of different types of capacity within the loop are likely to diverge very sharply from preattack price ratios if the destruction is heavily concentrated in a few industries. There would of course be a general tendency for viability prices to be higher in the industries that are hardest hit. In the capacity expansion loop, this tendency is compounded by the fact that the alleviation of the scarcity in the course of the reorganization period will be hindered by the vicious circle problem. Outside of the capacity expansion loop, total destruction of the capacity of an industry does not necessarily create more serious problems than an equal amount of destruction (at preattack prices) spread over several industries. In fact, the chief reason why total destruction of an industry's capacity outside the capacity expansion loop <u>might</u> pose more serious problems than evenly spread destruction is that the demands placed on the capacity expansion loop might be less evenly spread among the industries of the loop, thus compounding a vicious circle problem within the loop.

The Network Industries: Transportation and Communications, and Electric Power Distribution

These industries are all included in the capacity expansion loop, and the implications of severe destruction of either of them are obviously very serious.[1] The mental experiment of visualizing the economy suddenly deprived of the services of either of these industries, but otherwise intact, and then trying to think of how the situation might be remedied, is particularly sobering. These industries are particularly important to the process of getting started on the path to viability; they are not only essential to reorganization, they are essential to the effort to get organized for reorganization. Severe shortages in either of these industries would limit the effective use of surviving capacity and inventories of all other kinds, in the most extreme way. The physical basis for a coordinated national effort to achieve viability would not exist. Vicious circle problems might well exist at a very localized level: Two nearby cities, cut off from the rest of the country, might be able to provide mutual assistance that would ward off population losses if they could reconstruct the railroad line or highway between them. Part of the capability for doing so might exist in one city, while complementary capabilities, necessary to any progress, existed in the other. The link could be reconstructed if the capabilities could be combined, but the absence of the link would prevent this. Escape from the vicious circles would be possible only if, in some localities, there were economic and organizational resources to begin the process of restoring links and success in restoring these links quickly afforded access to additional resources that would permit the process to continue.

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[1] Communications and transportation are lumped together because an adequate system of communications would probably exist, or could be quickly created, if adequate transportation survived.

INDIVISIBILITIES AND INCREASING RETURNS

Any investment project is characterized by a high degree of indivisibility if a large investment of resources must be made before any output is forthcoming. If a situation is imagined in which the entire investment program for achieving viability consisted of a single project, the role of indivisibility can be phrased in very simple terms: the larger the amount of resources that must be invested in that project before any output is forthcoming, the larger must be the surviving inventories if the reorganization is to be achieved. For so long as no additional output is forthcoming, the resources to be invested in the project, and to support the population in the meantime, must come out of inventory. It must be emphasized that this consideration is quite independent of the productivity of the new capital in any other sense. If the project cannot be completed, it does not matter how dramatically output would increase if it were completed.

The assumption of a single project involves a great overstatement of the significance of indivisibility. If individual projects in a given industry are numerous and small in relation to the total amount of resources to be invested in that industry, the total investment may be divisible in the relevant sense. However, this will be the case only if the individual projects are actually close substitutes for each other, in the sense that the completion of any one of them would reduce the need for early completion of the others. In the absence of such substitutability, new capital in each individual project might be underutilized, at least until the entire program approached completion. The entire investment program would therefore yield only a small flow of output in relation to the capital investment made in the early stages, a result similar to what would occur if the program consisted of a single indivisible project.

An important example of this last possibility might be the restoration of damaged links to the transportation system. It might be virtually essential to restore certain links in spite of the fact that the traffic over them would be relatively small until well into

the recuperation period. If individual links were always close substitutes for each other, this would not happen; but many links may have a special purpose associated with their particular geographical location. This is often true of links that cross or circumvent natural barriers: the Soo Locks, the bridges across the Mississippi at particular locations, and so forth.

There are actually two distinct types of indivisibility that are relevant here. It has already been noted that a project may be indivisible in the sense that a large investment of resources must be made before any additional output is forthcoming. The second is that a project may be indivisible in the sense that it cannot be broken into sub-projects that can go forward simultaneously. This means that the time required to complete the project (and thus obtain additional output) cannot be reduced beyond a certain point by applying resources more intensively. Since the reorganization effort is a race between reconstruction and inventory depletion, this sort of phenomenon is a good deal more important in the reorganization context than it is under ordinary economic conditions. If inventories of subsistence goods will support the population for one year, and a project essential to the restoration of production of subsistence goods absolutely cannot be completed in less than two years, it does not matter how small an investment of resources the project represents; viability will not be achieved. More realistically, additional resources will always make possible somewhat earlier completion, but the addition to resource requirements resulting from the need for early completion may be what raises the total above availabilities. It is interesting to note that this sort of indivisibility in the time dimension can be regarded as self dependence in the application of effort to the project; there is a limit to the rate at which progress toward completion can be made that is independent of the availability of resources. Conversely, self dependence of an industry can be regarded as imposing this kind of indivisibility on the "project" of restoring its capacity.

The question of whether a particular project is or is not divisible in a relevant sense is basically a quantitative question. It would often be possible to reduce very substantially the initial investment that must be made in a project before some output is forthcoming, or to advance the completion date with no additional investment but at the expense of efficiency in operation, or of durability. Railways and highways could be built with much less attention to grading and to preparation of the roadbed, but at the expense of lower speeds and higher fuel and maintenance costs. Thus the peculiar economic exigencies of the reorganization period might force a resort to hasty, haphazard, shoddy, and inefficient ways of doing things (by engineering or preattack economic standards). As a result, the subsequent growth of the economy would be slower than if more time and resource-intensive methods had been employed during the reorganization period. Haste makes waste; but waste may be the price of survival.

TECHNOLOGICAL CHANGE

The discussion thus far has identified a large number of possible obstacles to the achievement of viability after a thermonuclear war. There are probably many more. It has been observed that, to overcome or circumvent these obstacles, it might well be necessary to resort to techniques of production that are known to exist, but are unprofitable under the existing pattern of scarcities and time preferences.

A possibility that is certainly of first order importance is that the production techniques used to overcome the unprecedented problems of the reorganization period may include not only techniques that are known but unused at present, but some that are not even known. The survivors of a thermonuclear war could be expected to exercise a good deal of ingenuity in coping with the problems confronting them, and they might well accomplish "miracles of production." A great deal more effort will be devoted to solving the problems of achieving economic viability if a thermonuclear war actually occurs than will ever be devoted to preparing to solve them. It is therefore reasonable to suppose that solutions will be found that are being completely overlooked in studies such as this.

The history of the war effort in any of the major belligerent nations of World War II provides strong support for the view that technology tends to rise to the occasion when new, difficult, and important problems are presented. Significant improvements in products and processes were made, many of them in response to resource shortages rather than to any more immediate problems in military technology. The Germans made major innovations in the use, and non-use, of ferroalloys; the Americans made great progress in improving synthetic rubber, and so forth. These examples drawn from wartime situations are only a part of the supporting evidence for a widely held and fairly well substantiated theory of the direction of technological change. This theory emphasizes the importance of profitability and "perceived need" in directing attention to technological problems, and the importance of allocation of attention among problems in determining the sorts of innovations that appear.[1] When one considers the multitudinous reasons why dramatic changes in the relative scarcities of different resources might be produced by a thermonuclear war, it becomes clear that profitability and perceived need would direct the attention of inventive minds to problems whose existence was never even imagined before the war. Many of these problems might be fairly simple; the explanation for their being unsolved at present is not that they are difficult, but that no attention has been devoted to them.

There is, however, no reason to suppose that miracles of production will necessarily occur in such numbers as to permit successful reorganization even in the most unfavorable circumstances. Innovation is scarce under any conditions, because the resources that produce it are scarce, it takes time, and the problem to be solved must be

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[1]For a survey of the evidence and a general discussion of the theory, see Richard R. Nelson, "The Economics of Invention: A Survey of the Literature," Journal of Business, April 1959, pp. 101-127; and by the same author, The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton University Press, Princeton, 1962, pp. 3-16.

identified. All of these considerations place limits on the amount of technological progress that would occur in the aftermath of a thermonuclear war. Indeed, a war in which extensive city attacks occurred might result in disproportionately high death rates among the scientific and technical elites of the nation, and in the skilled labor force of advanced technology industries. A large fraction of the nation's research facilities, including libraries, might be destroyed, and the normal processes of communication of scientific and technical information might become seriously disrupted. The possibility of technological regression rather than technological progress would clearly exist under sufficiently extreme conditions. Thus, no conclusion can be drawn without reference to particular assumptions about the extent and pattern of destruction. In this particular case, it is obviously difficult to draw conclusions even if specific assumptions are made.

VI. ALTERNATIVE PATHS TO ECONOMIC VIABILITY

After a thermonuclear war policymakers will have some difficult decisions to make about the general strategy to be pursued to achieve economic viability. Without any particular assumption as to the nature of the policy tools by which this strategy would be implemented,[1] some of the major alternatives that might exist will be briefly described. The selection of a particular strategy for viability would involve a series of tightly interrelated decisions as to the time paths of consumption, investment, and other claims for goods and services; these decisions would be, or would be thought to be, consistent with the time path of total availabilities -- inventories, imports, and new production. Inevitably, the decisions would be made under gross uncertainty. The wide range of possible situations that confront the analyst at present would have narrowed to a single situation, but the description of the situation available to decisionmakers might be incomplete or inaccurate in important respects. For example, there might not be accurate information available until long after the war on the surviving inventories of particular products, the amount of capacity in particular industries, or the skill distribution in the labor force.[2] The effectiveness of the government's administrative apparatus and the response of the population to various policy measures would not be accurately known. Finally, policymakers might be uncertain as to their own goals, particularly as to the relative importance of objectives that are partially conflicting.

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[1] Although the text refers repeatedly to policymakers "planning" the effort to achieve viability, it is not assumed that such planning would necessarily be implemented by detailed governmental control. It might be implemented by tax policy, by credit rationing, by negotiation and persuasion, or other means.

[2] For a discussion of the information requirements of planning for economic reorganization, see B. F. Massell and S. G. Winter, Jr., Postattack Damage Assessment; A Conceptual Analysis, The RAND Corporation, RM-2844-PR, November 1961.

Policies developed and pursued under conditions of gross uncertainty generally cannot be rationalized in terms of a single "best guess" as to what the future holds and the effects the policies will produce. Instead, they involve attempts to hedge against particularly unfavorable outcomes, to avoid final commitment to a course of action until better information is available, or to follow procedures that have some rationale in the behavior patterns of the past that may seem to compensate for the absence of any other rationale. In deference to this aspect of reality, no attempt will be made to keep this discussion of alternative paths to viability within the bounds of the simple characterization of the problem presented thus far. Instead, that characterization will be used as it might be used if it were understood and (in some sense) accepted by policymakers in an actual postattack situation: as a framework within which the central policy questions can be raised and discussed, rather than as a source of answers.[1]

SUBSISTENCE CONSUMPTION

A critical decision that would partially define a strategy for achieving viability would be the level of consumption allowed to the population. A naive application of the simple model might quickly lead to the conclusion that if there is any doubt about the outcome, consumption should be held at the subsistence level until that doubt is eliminated. This, however, ignores the fact that the "subsistence level of consumption" is one of the things about which there might be some doubt. Analysis of the conditions for economic viability is

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[1]It should be emphasized at this point that the subsistence consumption-fixed requirement-investment categorization of final demand is similar to, but not identical with, the usual consumption-government-investment breakdown. Subsistence consumption involves by definition the provision of consumption goods as a means of assuring the future supply of labor; investment involves by definition the attempt to maintain or expand productive capacity. Whether the expenditures are made by the government, firms, or individuals, is irrelevant for present purposes.

impossible without some concept of a subsistence level of consumption, but serious difficulties confront the attempt to give quantitative content to the concept. The operational definition here is that the subsistence level of consumption is the level necessary to prevent great reductions in the supply of labor available for continuing the reorganization effort.[1] Apart from the fact that the reduction in the supply of labor would be occurring continuously rather than discontinuously as consumption declined, this definition conveys precisely the meaning that is relevant from the point of view of economic viability. But this precision in principle makes the subsistence level of consumption depend, as a practical matter, on a wide range of considerations other than that provided by the physiological adequacy of the diet, shelter, clothing, and so on.

Clearly, if the consumption of the workers is physiologically inadequate, a reduction in the labor supply will occur as a result of failing health and death, so the subsistence level of consumption on the above definition is certainly no lower than that needed to meet the minimum physiological needs of the workers. Furthermore, for both moral and practical reasons, the workers' families must be provided for as well. Thus the level of consumption required to maintain the health of the workers and their families sets a lower bound to the level of subsistence consumption as defined above.

There is reason to believe that there would be great reductions in the supply of labor at consumption levels well above this lower bound. The level at which such reductions would occur depends upon the rewards and costs of participation in the reorganization effort as compared with those of various modes of nonparticipation, and, more fundamentally, upon the psychological sets and attitudes that determine

[1] The phrase "available for continuing the reorganization effort" is meant to cover the cases where workers may withdraw from the national effort (for example, by ceasing to work for money) and attempt to meet their needs on the basis of self sufficiency of a household, a locality, or a region. Such withdrawal could be economically rewarding for the individuals or groups concerned and be counterproductive for the nation as a whole.

how those rewards and costs are assessed. Whether a given amount and composition of consumption is above subsistence is likely to depend not so much on its physiological adequacy as on its relation to aspiration levels, which will in turn be influenced by the historical experience of higher levels of consumption, by views as to what can reasonably be expected under the circumstances, and by other factors. And, given the aspiration levels, the level of subsistence consumption may depend on such diverse things as the character and effectiveness of the rationing scheme (if any) for food and other necessities, the degree of voluntarism in the labor allocation mechanism, the resources devoted to maintaining law and order, the degree of confidence in the monetary system (and hence on success in controlling inflation), the level and structure of taxes, whether home gardening is encouraged or discouraged, whether persons in dire need are provided with necessities at no charge (or on how dire their needs have to be to make them eligible), and many other considerations.

The level of subsistence consumption will be increased by measures that reduce the dependence of an individual's command over consumption goods upon the productive effort he contributes to the economy. For example, it will be increased by free distribution of some consumption goods, by rationing schemes that make it difficult or impossible to increase one's consumption by increasing one's earnings, or by income taxation that is high and progressive at low income levels. A similar result will occur if price control and ineffective rationing lead to long queues at stores, or to localized imperfections in markets that make it necessary to spend time and effort searching for someone who has goods to sell. A breakdown of confidence in the value of money, resulting in an unwillingness on the part of sellers of consumption goods to accept money in payment, would certainly reduce people's incentive to work for money. It would also result in a diversion of effort into the mechanics of barter.

The level of subsistence consumption will also be increased by anything that increases the attractiveness of meeting consumption needs by means other than contributing to the reorganization effort.

Some quite disparate considerations can be grouped under this heading. A partial or complete failure to maintain law and order will make plunder a relatively more attractive way of meeting minimum needs, and may at the same time force people who already possess inventories of consumption goods or other forms of wealth to spend their time defending them. If rationing is ineffective or nonexistent, and large and obvious inequities in the distribution of necessities occur, various forms of economic and political coercion may appear to some groups to be the most promising means of improving their situation. Such coercion might take the form of strikes, demonstrations, and so on, and would certainly lead to reductions in the labor force actually at work. A quite different possibility might arise in the case of persons who had an opportunity to raise their own food, including farmers formerly specialized in some type of agriculture and accustomed to buying much of their food at the store. Anything that led such persons to doubt the wisdom of meeting their needs through the market exchange process might lead them to withdraw from that process and attempt a much higher degree of self sufficiency, and this would threaten the success of the struggle for viability in the economy as a whole.

The total amount of consumption goods needed to prevent great reductions in the supply of labor in the market economy depend on the equity with which those goods are distributed. When one person receives 3,500 calories a day and another receives 1,500, the result is certainly less favorable from the point of view of maintaining the supply of labor than if both received 2,500. But while greater equity in distribution is likely to reduce the total amount of goods required to meet subsistence consumption requirements for the population, schemes to achieve greater equity may reduce work incentives to some degree. Hence, what is gained in the form of reduced subsistence consumption requirements may be lost in the form of reduced production. There is no perfect solution to the problem posed by the competing requirements of equity and production incentives, but particular measures for postattack rationing, taxation, and wage and

price control may make compromises between these requirements that are reasonable or unreasonable, efficient or inefficient.

Not only will policymakers be uncertain as to the level of subsistence consumption (in the relevant sense), but in addition they will be uncertain about several other highly important considerations. First, they may not be fully informed as to the preattack level of inventories of various items, and even less well informed as to the amounts of surviving inventories. They will therefore be faced with the problem of deciding how to allocate a stock of goods in ignorance of its exact dimensions and composition. Second, they will have very little information as to the effectiveness of measures employed to control the rate of use of inventory, including those measures designed to achieve an equitable distribution of the necessities of life among individuals and regions. Thus they will have to face the possibility that whatever decision they make as to the rate at which inventories should be used, the actual rate will probably be different, and very likely more rapid. Third, major uncertainties will exist with respect to the rate at which new output will be forthcoming. This problem will be particularly troublesome in the case of agriculture, because of the great importance of food, the uncertainties to which production is subject even in peacetime, and the potentially great but imperfectly known effects of the war upon the natural environment.

To sum up, the problem faced by the policymakers will be akin to that faced by shipwreck survivors in a lifeboat: What assumption should be made as to when rescue (new production) will be forthcoming? If it can, with reasonable assurance, be expected at an early date, there is no point in suffering the hardship of going on short rations in the meantime. If there is a significant risk that survival will be a close call, the prudent course might be to assume the worst and use supplies as sparingly as possible. But unlike the shipwreck survivors, the policymakers will be uncertain as to what supplies are available, as to the effectiveness with which a rationing policy can be carried out, and the effects short rations may have on the willingness and ability of the population to carry out essential tasks.

Under the circumstances, a wide range of policies with respect to the level of consumption might be regarded as reasonable. Policymakers would have to attempt to balance the risks of prodigality against those of miserliness; and, above all, they would have to be prepared to adjust their policies as experience provided them with additional information.

THE FIXED REQUIREMENT

The fixed requirement plays a role in the analysis of economic viability that is only slightly less essential than that played by subsistence consumption. To assume that an economy is viable if it is merely capable of supporting the population is to ignore the fact that most of the historical instances of economic collapse occurred when major efforts were being made to meet national needs other than the support of the population. The crucial question is not how total output (net of depreciation) relates to subsistence consumption requirements, but how actual consumption relates to subsistence consumption requirements. If, as a matter of national policy, nonconsumption claims on net output are being taken "off the top," then a cumulative downward spiral could well start from a point where output exceeded consumption requirements. But there would not in reality be any readily quantified fixed requirements that would stand out as the only nonconsumption uses of output of comparable urgency to subsistence consumption. Policymakers would not have the benefit of knowing which claims, if any, were of such importance as to deserve this status. Perhaps, if they had full knowledge of the consequences of their decisions, they would treat all other national objectives as secondary to the objective of successful reorganization. But in the actual situation, it would never be known with certainty whether the economy was just at a point where it could barely achieve viability. In some cases, a decision to ignore some claims on output or inventories would involve suffering immediate losses with certainty in order to reduce the likelihood of suffering much larger losses at

some future time from failure to accomplish reorganization. It is not obvious that such decisions would, or should, always be made.

The types of claims that might plausibly be treated as fixed requirements would be the support of nonproductive elements in the population, support of a military and/or arms control capability, and aid to other nations, probably in that order. With respect to the support of nonproductive elements in the population, some very difficult decisions might have to be faced. Providing the necessities of life for at least the healthy members of the families of individuals who were making some economic contribution would be a necessity, but the situation is not so clear with respect to the quality of the care that would be provided to persons disabled by injuries received in the war, and to the amount of aid that would be provided to isolated communities or regions that could not be readily integrated into the reorganizing economy, but were not self sufficient.[1] If the economy were otherwise in sufficiently dire straits, meeting these human needs to the maximum extent possible in the short run could well produce an almost total catastrophe in the long run. But the viability implications of any particular level of the fixed requirement would not be known with certainty. Food and medicine withheld from unproductive survivors, in anticipation of still more urgent needs in the future, might turn out to be superfluous. There would obviously be a great deal of room for reasonable men to disagree as to the course that should be taken in a situation of this sort. Some might argue that the reasons for believing that more urgent needs would be encountered in the future could never be so persuasive as to justify a refusal on the part of the more fortunate survivors to assist and sustain their fellow men; others might say that the risk of a total failure in reorganization should be minimized regardless of the immediate consequences.

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[1]This last issue is discussed below.

In the aftermath of a future war, the nation might be forced to devote a significant amount of resources to the support of a military establishment. The least favorable situation would be one in which it appeared that the Soviet Union might have the capability and inclination to resume the war at an early date. The effort to reconstitute some sort of deterrent force would compete very strongly with the attempt to achieve economic viability. Such a situation would obviously have a very high potential for ending in a total catastrophe, but the assumption that the Soviet Union would have either the capability or the inclination to resume the war does not appear very plausible. However, it is reasonable to assume that the international environment would be such as to make it desirable to maintain strategic forces not expended in the war, to restore communications, to keep track of developments in the Soviet bloc, and, of course, to enforce the terms of any cease-fire agreement. Even these limited requirements might be very hard to meet, and decisions relating to them would be made under the same sort of uncertainty with respect to viability implications that were noted above.

It should be emphasized that the requirements of economic viability and military power would be in conflict only to the extent that a military capability was needed during the reorganization period itself. No matter what the size of the military forces needed in the long run, achievement of economic viability would obviously be a necessary precondition for creating and supporting those forces. Although the character of the international environment in the long run might be an important determinant of the rate of recuperation, decisions made during the reorganization would be very little influenced by expectations about threats that might possibly be faced five, ten, or twenty years in the future.

It seems unlikely that the United States would run significant risks of failure in its own reorganization effort to help another country, if humanitarian motives alone were involved. However, it is possible to imagine situations where humanitarian and strategic motivations combined might lead the United States to run some risks.

For example, suppose a thermonuclear war broke out by accident in a period of extreme tension during a conventional war in Europe, and that the nuclear exchange were terminated before either the United States or the Soviet Union had been greatly weakened. The United States might then have both the incentive and the ability to concern itself with balance of power in Europe, just as it did after World War II. It would not deliberatly engage in such a great effort as to make the economy nonviable, but it might well run significantly greater risks than if the future of Europe were of no importance.

Another situation in which aid to other countries might play an important role would be one in which the United States committed itself to a cooperative reorganization effort with one or more other countries (for example, Canada), perhaps in the belief that the result in the long run would be a more rapid rate of recuperation. The short run result might be to make reorganization more difficult in the United States. In general, however, it seems likely that many fewer risks would be involved in assisting other countries than would be involved in sustaining unproductive survivors, or supporting a military capability. And if, as a result of an underestimate of the difficulty of reorganization, the United States overcommitted itself to an effort to help other nations, it seems likely that it would retreat from this policy as soon as the seriousness of the risks became apparent. Such a retreat might not be made in the other two cases.

INVESTMENT

The third major category in the nation's strategy for achieving viability consists of decisions about the size, timing, and composition of the investment program to be undertaken in order to create needed capacity. Since the policymaker's knowledge of the surviving resources and the production possibilities available in the economy would be incomplete, the planning of the investment program would take place under uncertainty as to both the feasibility of alternative programs and whether the economy would actually become viable

if the program were completed. Devoting more resources to the investment program would reduce the uncertainty about its feasibility and adequacy, but only at the expense of increased uncertainty about the adequacy of consumption, or of foregoing other urgent demands on the economy.[1] Furthermore, although the simple model of the situation does not suggest this fact, the size and character of the investment program would be influenced to some extent by views as to the desired capabilities of the economy after viability was achieved. A program that would provide a high probability of success in achieving viability might leave the economy less well equipped for rapid recuperation (or for increased consumption or national security expenditures) than a more risky policy.

The term "recuperation potential" will be used to refer to the value at preattack prices of the largest gross national product that it would be technologically feasible to produce after two decades of recuperation. This definition provides a conceptual basis for discussing the "size" of the economy when viability is achieved, over a range of situations that may involve drastic variation in the composition of the output the economy is capable of producing and in the relative prices of different resources. It abstracts from the short run distortions in the economy by valuing output at preattack prices and by referring to the state of the economy a long time after the war, and it abstracts from the possible differences in recuperation policies by assuming a social objective of recuperation at the maximum feasible rate. Other things equal, a path to viability that left the economy with a higher recuperation potential would generally be preferred to one that yielded a smaller recuperation potential, even though recuperation at the maximum feasible rate might not in general be the national objective. The economic capabilities that would make possible a higher GNP in two decades would also tend to

[1] Of course, the apparent reduction in uncertainty about whether the investment program could be accomplished would be spurious if the subtraction of resources from consumption led to great decreases in the available labor force.

make possible a more desirable combination of recuperation, increases in consumption, and satisfaction of other national needs. However, the state of the economy at the end of the reorganization period obviously depends to some extent on preferences among various uses of output thereafter. For example, if an immediate rise in consumption rather than rapid recuperation were the highest priority objective, inessential capacity in consumption goods industries would be valued more highly in relation to inessential capacity in the capacity expansion loop.

Decisions about the intended geographical scope of the viable economy would involve a complex balancing of considerations of recuperation potential, probability of success in achieving viability, and the other claims on output. First of all, recuperation potential will generally be higher if it is possible to draw all or nearly all of the surviving resources into the productive process than if it is necessary to write off surviving resources in some regions or localities. It might appear that it would always be desirable to make full use of everything that survived, but this view ignores the fact that the short run costs of putting some resources to work may far exceed the returns, and the essence of the problem of achieving viability is that great weight must be given to short run considerations. For example, restoration of the transportation links and utilities serving surviving capacity in an isolated undamaged area might require resources that could not be spared during the reorganization period; and if the reorganization effort took a different path, perhaps by expanding similar capacity elsewhere or adjusting to its absence, it might not pay to restore that part of the surviving capacity at all. Roughly the same problem might arise if capacity survived in an area where there were not enough workers to operate it. Even if the required labor force existed somewhere else, the costs to the reorganization effort of relocating a large number of workers might be excessive. Since capital goods undergo physical depreciation with the passage of time and retarding such deterioration requires resources, abandonment might be a more attractive policy than restoration.

The geographical scope of the economy is closely related to the fixed requirement for support of nonproductive survivors. Some survivors might be nonproductive because they were in a region that was cut off from the rest of the economy, or the surviving capacity were of a type that would make little contribution to reorganization. In an extreme form, the region might constitute a drag on the reorganization effort in the sense that it would be easier to achieve viability in the rest of the economy if the region, and its population, were simply written off. If such a policy were regarded as unacceptable, however, the burden of supporting the population of the region would have to be borne by the reorganizing economy regardless of whether the people were productively employed or not. Whether resources of the region should be exploited would then depend not on whether inclusion would make the total reorganization problem simpler, but on whether the people of the region could make a contribution to their own support that would more than offset the investment costs of putting them to work. If they could not, their support would be a part of the fixed requirement, but if they could, the region would be integrated into the reorganizing economy. Thus a decision to support survivors regardless of their productivity is likely to lead to an attempt to achieve viability with an economy of wider geographical scope, and probably of higher recuperation potential. But the cost of such an attempt would be an increased risk of a total failure.

Decisions as to the techniques of production to be employed in subsistence loop industries, particularly in agriculture, might also involve a balancing of the advantages of higher recuperation potential against the risks of a catastrophic failure. The central question here is whether the surviving industrial capacity will be sufficient to make possible the restoration of a mechanized agriculture and interregional specialization in the time available for reorganization, or whether the economy would be forced into much more labor intensive methods and a high degree of local or regional self sufficiency. The latter situation would involve a drastically lower recuperation potential than the former; first, a great deal of

surviving capital would be left idle, and second, a large part of the labor force would be required in agriculture. Yet for some patterns of destruction, this sacrifice of recuperation potential might have to be made in order to minimize the risk of drastically inadequate food supplies. The available resources of the economy might be better adapted to the task of shifting the surviving population into agricultural areas and producing hand tools, than, for example, to the task of rebuilding petroleum refineries and food processing plants. Although it seems unlikely that a reversion to primitive methods in agriculture would appear attractive, it is reasonable to suppose that the economy might well go in this direction if the breakdown of transportation, communications, and government organization divided the country into a large number of islands of survival. Once this tendency were well developed, it might remain the surest path to viability even if transportation, communications, and government were partially restored.

Another issue to be faced in choosing a path to viability would be how much effort should be devoted to projects that were inessential to viability. The economy might be unable to meet some essential needs out of current production for months or even years after any crisis stage of the reorganization effort had passed, simply because it appeared that it would unquestionably be possible to produce the required amounts when necessary, and inefficient to do so before then. In the meantime, capacity might be built beyond essential levels in other industries. But this sort of situation blends by degrees into one in which the devotion of additional resources to inessential projects would imperil success in reorganization if certain unfavorable circumstances arose; for example, if bad weather reduced the harvest to well below normal yields, it might turn out that resources should have been devoted to farming more acres instead of to inessential recuperation projects. Another way of looking at these problems is in terms of the amount of resources that should be devoted to expanding the margin of safety between the expected future

path of the economy and a path that would lead to collapse. If decisionmakers are willing to allow certain inventories to fall to critical levels before restoring production to the level of essential needs, more resources will be available for inessential projects than if as large a buffer is kept as possible.

Self dependence in the capacity expansion loop, and indivisibility of important investment projects, may result in very high returns in recuperation potential from an early start on some essential projects. Several years of recuperation time might otherwise be spent simply in expanding a few of the hardest hit industries to the point at which a more balanced expansion of industry as a whole would be possible. Meanwhile, capacity would be idle, and perhaps deteriorating, in other industries. Similar problems might arise in the choice of the sequence in which certain essential projects would be carried out. Because of dependence relations, or indivisibilities of various kinds, it might be much less expensive in resources to do project B after completing project A than to do the two simultaneously or to do B first. But the question would arise whether it would be safe to postpone the completion of B that long, and the answer might depend very critically on the levels and rates of use of certain inventories. Considerations such as these would increase the temptation to assume that essential projects would not run into difficulties, and to devote some resources to projects that would enhance recuperation potential.

To sum up, policymakers attempting to determine the path to viability would face difficult choices at every turn. Reductions in probability of a major failure in the reorganization effort might be purchased at a high price in terms of other national objectives -- the needs of unproductive survivors, the demands of short run national security, and the requirements of rapid recuperation. Furthermore, many critical and irreversible decisions would have to be made quite early in the reorganization period, before it was easy to determine how close the economy might be to the margin of viability. Resources

invested in restoring transportation and utilities in a particular region would not be recoverable if it later turned out that the surviving population of the region should be relocated and the industrial capacity written off; resources devoted to building steel plants, on the assumption that petroleum production would be adequate, could not suddenly be converted into refineries if the assumption proved false; and so on, in one difficult choice situation after another. Although the discussion has been confined to a description of some of the broad policy alternatives that might exist, the problems that would arise could not be considered in isolation from the problems of economic policy at a more detailed level, such as the effectiveness of arrangements for rationing necessities and controlling inventories. The choice among the policy alternatives identified above would be influenced by the same considerations that bear on the choice of organizational arrangements for controlling or guiding economic activity.

VII. A QUANTITATIVE PERSPECTIVE

In the preceding discussion, the major determinants of the technological feasibility of reorganization have been examined in theoretical and conceptual terms. This discussion amply demonstrates that, in principle, it is a difficult problem to assess the prospects for achieving viability. In fact, however, the problem may actually be simple, given a particular set of assumptions about the economic situation at the end of the survival period; for the facts may point so clearly in one direction that an exhaustive analysis of all the conceivable problems that might arise is unnecessary. Also, it has been noted that appropriate preparedness measures may simplify a situation otherwise difficult to analyze.[1]

In order to separate the cases in which the outcome can be determined with reasonable assurance from those in which it is more or less doubtful, the range of situations that may arise must be examined in quantitative terms. The quantitative perspective in the following pages provides only a rather gross view of the possible economic effects of a thermonuclear war -- because of limitations both of space and of available information. Nevertheless, the facts do point to some general conclusions about the feasibility of reorganization under various postattack conditions. At the end of the section, I present my own judgments as to the range of situations where successful reorganization might be expected with reasonable confidence, and identify what seems to me to be the major uncertainties that arise in other situations. Since the evidence presented falls short of providing conclusive documentation for these judgments, the reader is, of course, free to draw his own conclusions.

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[1]To take a simple and important example, it would be difficult, if not impossible, to develop a quantitative estimate of the consequences of a severe shortage of communications channels. But a preparedness program that assures either the survival or the quick restoration of adequate communications eliminates this source of uncertainty about the success of the reorganization effort.

SURVIVING POPULATION AND RESOURCES

The relationships between surviving economic capacity and population that might result from various levels and types of nuclear attack on the United States will be examined first. Together with the size of the fixed requirement and the per capita level of subsistence consumption, this relationship determines the amount of reconstruction necessary to make the economy viable. The questions of what the fixed requirement and the level of subsistence consumption per capita might be will be dealt with subsequently, but it may be remarked in passing that since the United States is a very wealthy and productive nation, its present productive capacity far exceeds the amount needed to support its population at a physiological subsistence level and meet a fixed requirement of substantial size.[1] Therefore, great losses of capacity could occur without making the economy nonviable (for technological reasons) even temporarily, let alone permanently, provided that the losses occurred in the right industries and provided that the subsistence level of consumption is not too far above physiological subsistence. To illustrate, the output required to provide a 1929 level of real consumption per capita for the entire 1960 population, plus meet a fixed requirement equal to 1960 government expenditures on goods and services, plus provide for depreciation to the extent of 1960 capital consumption allowances, equals only 63 per cent of the output that the economy could have produced in 1960 if it had been at full employment.[2]

The balance between surviving productive capacity and population after a nuclear war would reflect the influence of two fundamental facts. The first is that the area in which lethal effects to unprotected personnel would result from the local fallout of a large yield nuclear weapon (surface burst) greatly exceeds the area in which

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[1]"A fixed requirement of substantial size" means a requirement equal to perhaps 10 per cent or more of preattack GNP -- about the magnitude of current defense expenditures.

[2]This comparison assumes that full employment GNP in 1960 was $534 billion (in 1960 prices), interpreting full employment as an unemployment rate of 4 per cent.

serious damage to structures and equipment from blast and thermal effects would occur.[1] The second is that the nation's productive capacity, except for agriculture and extractive industries, is in general more highly concentrated in and near large cities than is the population. Taken together these facts imply that the percentage survival of population may be expected to be high relative to survival of productive capacity if the population is well protected, at least against fallout, and the attack is directed against cities; whereas if the population has little protection and the attack is largely against military installations, a larger proportion of capacity than of the population is likely to survive. Other combinations of circumstances -- a substantial attack against cities, in a situation where little fallout protection is available, or an attack directed mainly at military targets when the population is well protected -- may produce an over-all balance between postattack population and capacity similar to that which existed preattack.[2] Note, however, that in the former of these two cases the balance exists because survival of both population and capacity is low, while in the latter it exists because little of either is destroyed. Even from the narrow point of view of determining the feasibility of reorganization -- let alone in judging the total effects of the war -- it would be a great mistake to regard these two situations as equivalent. For when the total destruction is high, the prospects for reorganization are adversely affected by considerations other than the over-all balance between population and capacity. Severe bottlenecks in particular industrial categories and skill groups are more likely, the disruption of transportation and communications is increased, and solution of the strictly organizational aspects of the problem is greatly complicated.

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[1]For a ten megaton weapon, surface burst, the blast effects (2 psi) might cover 350 square miles, thermal effects (20 cal/cm^2, 50 mile visibility), 700 square miles, lethal radiation effects, perhaps 4500 square miles.

[2]Actually, the effect of greater concentration of capacity would probably dominate the results in the case of an attack exclusively against cities, even if the population were unprotected. However, a city attack designed to exploit fallout as a lethal effect might result in about equal survival of population and capacity.

The curves in Figs. 4-10 provide a rough indication of the percentages of preattack population and various types of industrial capacity that would survive various weights of attack, on the following assumptions: (1) The attack is directed against concentrations of population and industrial capacity; military targets, per se, are not attacked. (2) The entire population is provided with high quality fallout shelter; that is, approximately the shelter provided by a specially constructed home shelter. This shelter is assumed to provide modest blast protection as well, at least in the case of shelters on the periphery of target areas. (3) All weapons are of 10 MT yield, and are delivered right on target.[1] These assumptions correspond to a situation that would tend to result in quite high levels of survival of population in relation to industrial capacity. Higher levels of population survival, for a given weight of attack on urban targets, could result only if the cities were evacuated or if their populations were provided with substantial protection against blast and thermal effects. An attack directed in part against military targets, and/or a situation in which the protection of the population was less adequate than assumed here, would result in higher levels of survival of capacity in relation to population.

The survival of each type of capacity and of population is shown for two enemy targeting strategies. The higher curve on Figures 4-10 shows the results that would occur if a given number of target areas were attacked, each with one 10 MT weapon, and the areas attacked were those containing the largest populations. The horizontal coordinate shows the percentage of the population, the vertical coordinate shows the percentage of capacity that would survive. The lower curve shows the result if the target areas attacked were those containing the largest amounts of capacity, thus the percentage of capacity surviving is lower and the percentage of the population surviving is higher than shown in the upper curve. The numbers along the curves

[1] See Appendix C for a more technical account of how the curves were derived and how they should be interpreted.

indicate the scale of attack (in terms of number of target areas attacked) that would produce the indicated results.

Figure 4 shows the percentage survival of population and of survival industry. The latter is an aggregate of various three and four digit (Standard Industrial Classification) manufacturing industries considered essential or important to the support of the population -- food processing industries, textiles and apparel industries, surgical instruments, drugs, transformers, hand tools, oil burners, and so on.[1] The measure of capacity is manufacturing value added. The higher curve shows, for example, that an attack on the 50 target areas ranking highest in population would leave about 72 per cent of the population surviving and 62 per cent of the survival industry capacity. According to the lower curve, if the 50 areas ranking highest in survival industry capacity were attacked instead, 78 per cent of the population would survive, but only 56 per cent of the survival industry capacity.

"Survival curves" like those shown in Figs. 4-10 provide a simple way of determining the level and pattern of attack that would result in less survival of capacity than would be necessary to meet some particular, population-related requirement. For example, suppose that it is determined that viability would require that .5 per cent of preattack survival industry capacity survive for every 1 per cent of the surviving population. Any point on or above a "requirements line" drawn on Fig. 4 from the origin to the point (100, 50), that is, 100 per cent population survival, 50 per cent survival of survival industry, satisfies this condition. This line does not intersect the higher curve, hence an attack directed against population would always permit this requirement to be satisfied. However, an attack against survival industry involving two hundred or more targets would make it impossible to satisfy the requirement without some reconstruction. The population attack curve in Fig. 4 lies entirely above the line corresponding to a requirement of .7 per cent of preattack capacity for every 1 per cent of population survival, and the survival industry attack curve

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[1] For a listing of the content of the survival industry aggregate in terms of SIC categories, see Table 11.

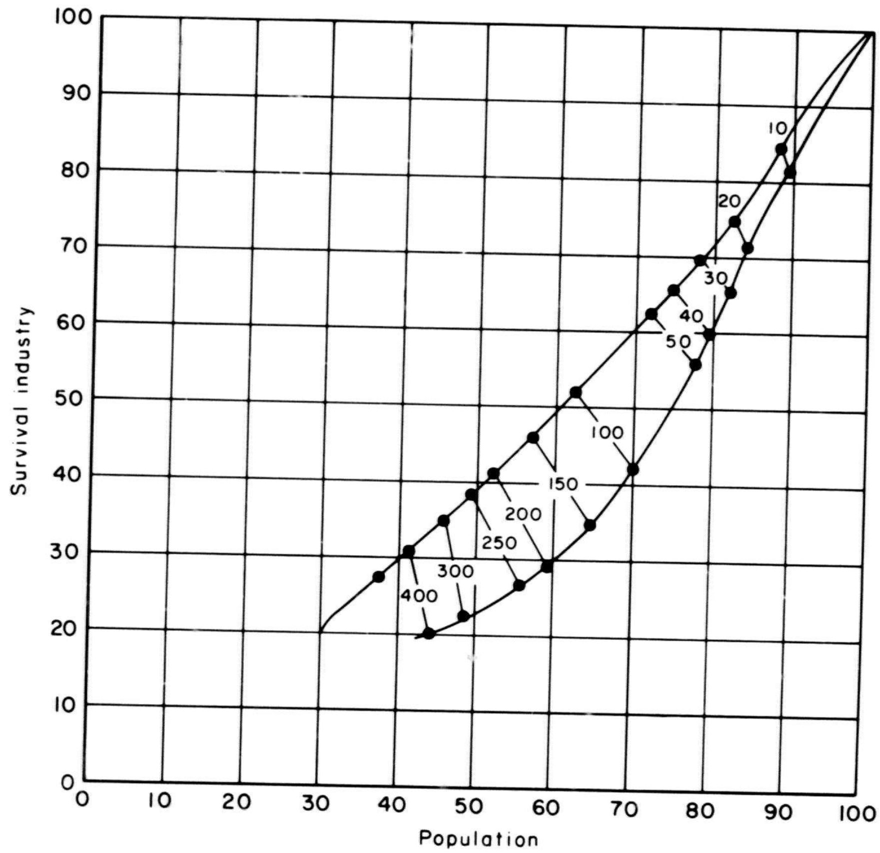

Fig. 4 — Survival curves for attacks on population and on survival industry
(per cent surviving)

lies above a line corresponding to a requirement of .45 per cent. Compared with some of the industrial categories to be considered subsequently, the geographical distribution of survival industry corresponds quite closely to that of the population.

Conclusions such as those just stated are conditional on the particular assumptions made, and even on those assumptions are subject to a significant range of error. Detailed analysis of the results of particular attacks would have to be undertaken in order to provide a more substantial basis for such conclusions. In particular, the determination of the level of attack that would reduce the ratio of surviving capacity to population below some given requirement is subject to a large error when the survival curve is roughly coincident with the requirements line over a considerable range -- as is the case with the higher curve in Fig. 4 and a .75 per cent requirement line. If actual population survival deviated by only a few percentage points one way or the other from the level shown by the curve, the level of attack that would make it difficult to meet such a requirement would change by a large factor. However, the type of analysis made above provides a rough picture of a wide range of situations that is difficult to derive from the mass of detail involved in the analysis of particular attacks.

Figure 5 shows survival curves for population and recovery and military support industry, an aggregate made up of industries essential or important to economic recovery and the support of military forces, with the exception of petroleum refining and the survival industry aggregate. The categories are primarily heavy industry -- ordnance, iron and steel, machine tools, aircraft, railroad rolling stock, farm machinery, motor vehicles, and so on.[1] The measure of capacity, again, is manufacturing value added. Recovery and military support industry is significantly more concentrated than survival industry and the population. Less than half of preattack capacity would survive an attack against the 50 target areas containing the most capacity.

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[1]For a listing of the categories, see Table 12.

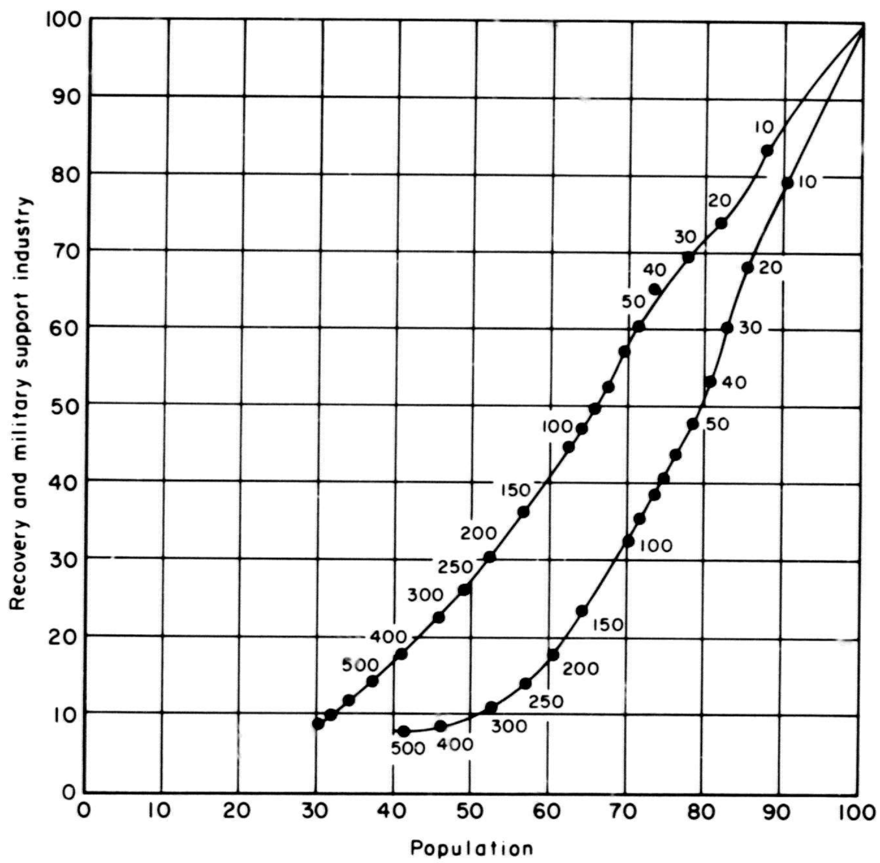

Fig. 5 — Survival curves for attacks on population and on recovery and military support industry

(per cent surviving)

If, as seems plausible, some capacity in recovery and military support industry would be needed to meet the fixed requirement, the line expressing the requirement for recovery and military support industry as a function of population survival does not pass through the origin. Suppose that the fixed requirement is for 35 per cent of preattack capacity, and, in addition, .4 per cent of recovery and military support industry must survive for every 1 per cent of the population that survives. A line from (0, 35) to (100, 75) expresses this requirement. Survival of capacity is less than the required amount if the 50 top population targets are attacked, or if the 20 top recovery and military support industry targets are attacked. A reduction of the fixed requirement to 20 per cent would more than double the attack levels that would reduce surviving capacity below the requirement, and complete elimination of the fixed requirement would again multiply those attack levels, by factors of five and three. Thus, fixed requirements of quite moderate size, relative to preattack capacity, may greatly decrease the attack levels that would be large enough to reduce surviving capacity below the required levels.

Figures 6 and 7 show survival curves for petroleum refinery capacity and electric power generating capacity, respectively. The capacity measure for the latter is kilowatts of installed capacity; for the former it is crude throughput (thousands of barrels per day). The two cases contrast very sharply. Petroleum refining is highly concentrated and quite well separated from the population. As a result, a requirement for, say, one-half of the preattack per capita capacity could be met even after very heavy attacks if the attack were directed against population. But surviving capacity would fall below such a requirement if fewer than 20 of the top petroleum refining targets were attacked. Electric generating capacity, on the other hand, is quite well dispersed over the country, and it is collocated with the population to a substantially greater extent. In an attack directed against population, generating capacity survives in greater proportion than population. And attacks directed specifically at generating capacity would leave preattack capacity per capita at more than half of its preattack value, even for quite heavy levels of attack.

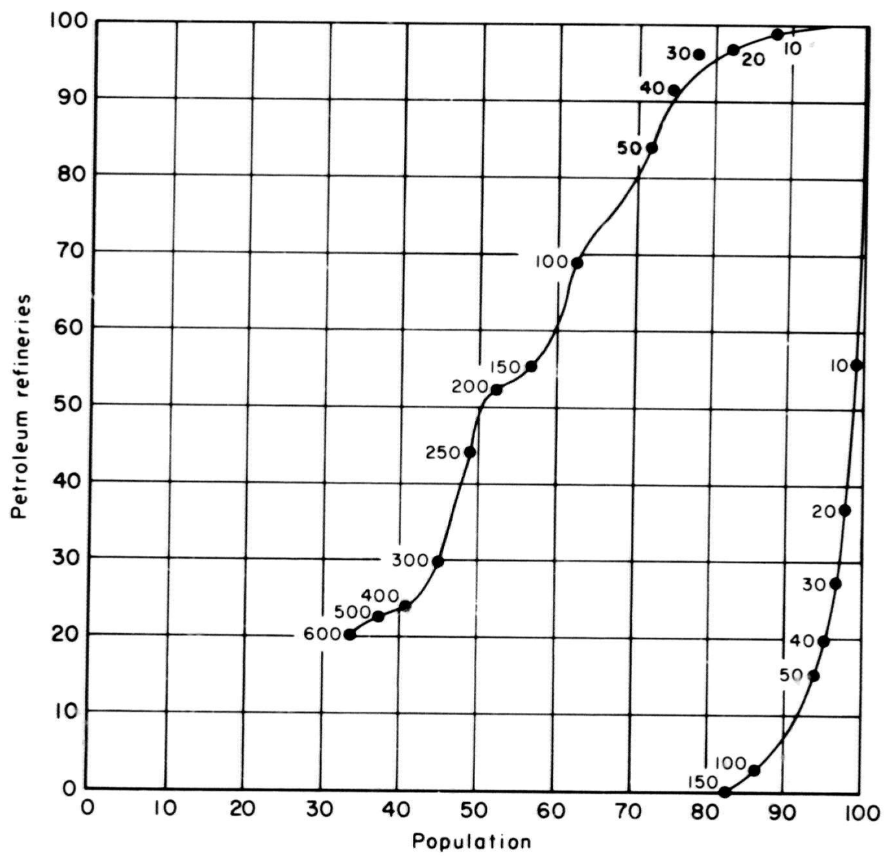

Fig. 6 — Survival curves for attacks on population and on petroleum refineries

(per cent surviving)

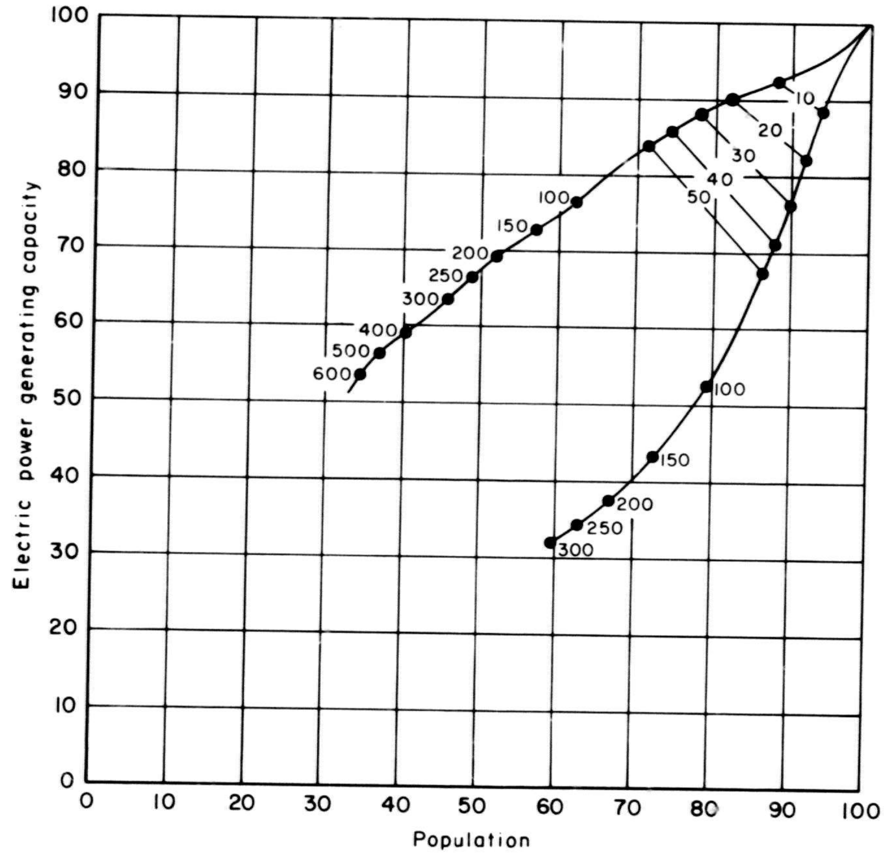

Fig. 7 — Survival curves for attacks on population and on electric power generating capacity
(per cent surviving)

It should be noted that an attack directed specifically at a particular type of industrial capacity is not necessarily the worst possible attack from the point of view of minimizing surviving capacity per capita. An attacker who adopted such minimization as the criterion for his targeting strategy would want to avoid attacking target areas with large populations, even if they contained significant amounts of the type of capacity in question.[1] Figures 8 and 9 show survival curves resulting from "population avoidance" attacks on the four industrial categories examined above. The areas in the target list at the indicated levels of attack are those that have the greatest difference between the percentage of the particular type of capacity and the percentage of the population located in the target area. For example, an area containing 1 per cent of the nation's generating capacity and .5 per cent of the population would be higher on the electric power target list than one containing 1.5 per cent of the generating capacity and 1.25 per cent of the population.

In a comparison of Figures 8 and 9 with Figures 4 through 7, it is found that the population avoidance attacks do not, for the most part, produce results greatly different from those of the simple attacks against the various industrial categories.[2] The major exception is electric power generating capacity, where the population avoidance attack may increase population survival, at some levels of survival of generating capacity, by more than ten percentage points. There are quite a few target areas with substantial amounts of electric power generating capacity and very small populations that are not close

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[1] To be precise, the attacker would refrain from adding a given target area to his target list if the percentage reduction in population survival produced by attacking it would exceed the percentage reduction in survival of the particular type of capacity (taking the rest of the target list as given). The line of reasoning that might lead an attacker to adopt such a targeting strategy was summarized in Section IV.

[2] However, because of the particular assumptions on which these curves were derived, it is possible that Figures 8 and 9 very substantially understate the possibilities for minimizing surviving capacity per capita. See the discussion in Appendix C.

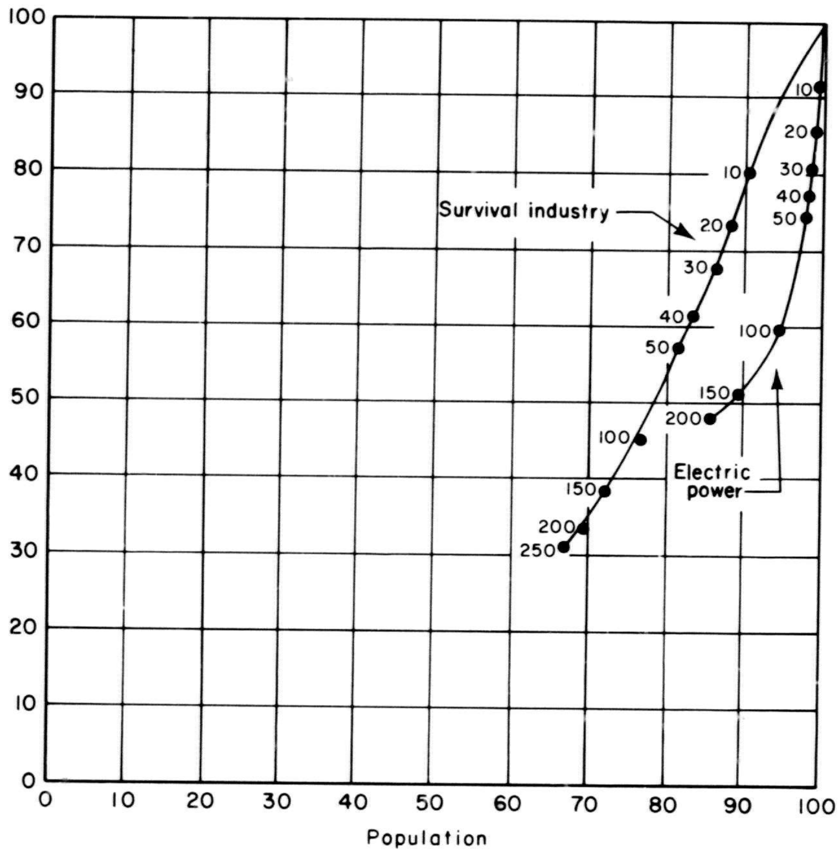

Fig. 8 — Survival curves for population avoidance attacks on survival industry and on electric power generating capacity (per cent surviving)

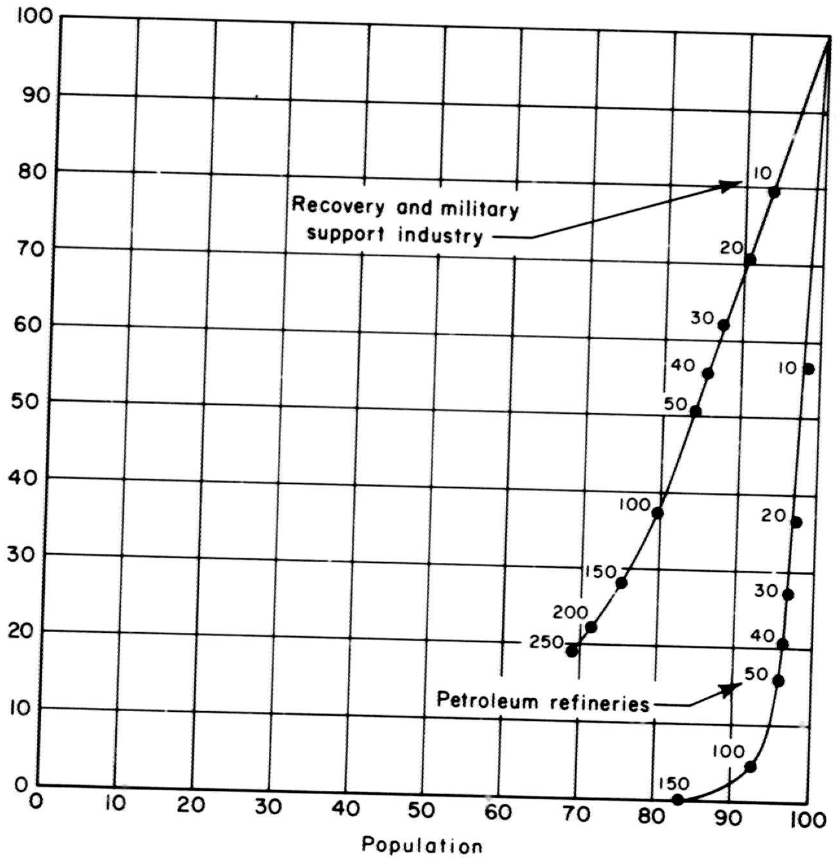

Fig. 9 — Survival curves for population avoidance attacks on recovery and on military support industry and on petroleum refineries (per cent surviving)

to the top of the list based on generating capacity alone. In the case of recovery and military support industry, the population avoidance attack increases population survival by more than five percentage points at levels of capacity survival between 20 and 40 per cent. However, the attack levels that would reduce capacity below a requirement of .4 per cent for very 1 per cent of the surviving population (plus a fixed requirement between 0 and 35 per cent) are essentially the same for the population avoidance attack as for the simple attack. The increase in the number of weapons needed to achieve a given reduction in surviving capacity cancels out the effects of increased population survival.

If the United States were forced to rely heavily on imports to overcome severe bottlenecks during the reorganization period, it would need to have surviving port facilities through which to move the goods. The survival curves in Fig. 10 point to the unsurprising conclusion that the nation's port capacity (measured by number of berths for ocean going vessels) is highly concentrated, and much of it is in areas of heavy population. An attack against the top 50 population targets would reduce port capacity to about 30 per cent of preattack, and an attack against the 50 target areas ranking highest in port capacity would wipe out that capacity completely. Since the possibility that the United States could turn to overseas sources for items that were in critically short supply is a major qualification to the argument that a bottleneck attack might make reorganization impossible, it is important to note that this qualification is itself subject to qualification because of the high geographical concentration of our port facilities. Less than 175 ten megaton weapons perfectly delivered could wipe out all U.S. refineries and port facilities.[1] Although limited amounts of port capacity could undoubtedly be improvised in a short time, it seems unlikely that efforts at improvisation would be effective enough to make importation on a large scale possible during the reorganization period.

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[1]And less than two hundred would destroy all the ports and refineries in the United States and Canada together.

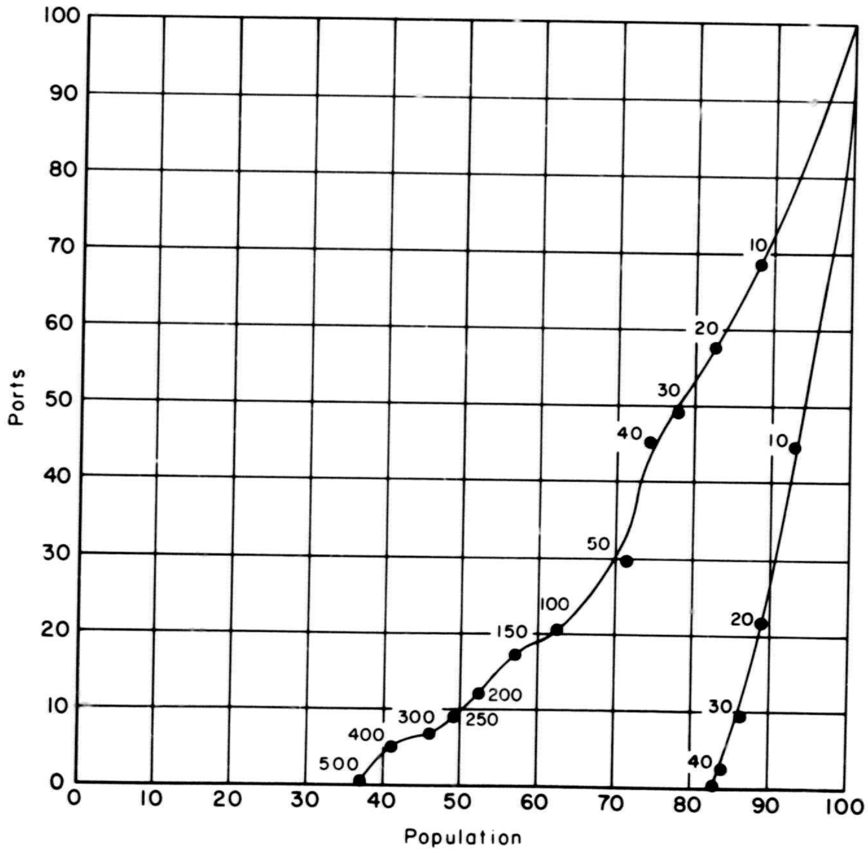

Fig. 10 — Survival curves for attacks on population and on port capacity

(per cent surviving)

SUBSISTENCE CONSUMPTION: REQUIREMENTS, INVENTORIES, RESUMPTION OF PRODUCTION

Requirements

Section VI discussed the various reasons why the relevant concept of subsistence consumption for the purposes of viability analysis is not a physiological concept, and the complications introduced thereby. In the quantitative discussion in this section, no particular level of per capita consumption expenditures is defended as a plausible value for subsistence consumption in the relevant sense, nor, of course, is there any attempt to quantify the influence of any of the organizational factors that have been mentioned. Instead, the implications of alternative specifications of the level of subsistence consumption are indicated in terms of the extent of the setback in the historical rise in living standards that would be involved, and the percentage of 1960 GNP required in order to provide various specified levels of consumption for the entire population. The feasibility of holding per capita consumption above a particular level after various nuclear attacks is then investigated. The primary reason for choosing this particular level of consumption for detailed analysis is that it allows use of previous work on the subject; but it is believed that the analysis illuminates an interesting range of situations. Finally, a historical perspective is provided on the extent of the adjustments in the average diet of the population that might be acceptable in a postattack situation.

The standard of living in the United States today is unprecedented and unparalleled. Table 1 indicates that per capita personal consumption expenditures in 1960 were almost 2-1/2 times as large as in the years 1902-1906, and about 1-3/4 times as large as in the middle 1920s. If it is assumed that the standard of living that was typical in the United States in the early years of this century would be acceptable to Americans in a postattack situation in the 1960s or 1970s, it might be concluded from Table 1 that the ratio of surviving productive capacity to surviving population would have to fall to

Table 1

PER CAPITA PERSONAL CONSUMPTION EXPENDITURES IN THE UNITED STATES AND PER CENT OF 1960 FULL EMPLOYMENT GNP IMPLIED FOR FULL 1960 POPULATION 1902-1906 - 1960

Year	Per capita personal consumption expenditues in 1954 dollars	Per cent of 1960 GNP[a]	Year	Per capita personal consumption expenditures	Per cent of 1960 GNP[a]
1902-1906	$677	26	1929	$1052	41
1907-1911	734	28	1933	824	32
1912-1916	765	29	1940	1095	42
1917-1921	809 (766)[b]	31	1945	1225	47
1922-1926	947	36	1950	1430	55
1927-1931	1014	39	1955	1549	60
			1958	1572	61
			1960	1650	64

Notes:

[a]Per capita expenditure levels times the 1960 population residing in the United States as a percentage of estimated full employment GNP in 1960 ($467 billion 1954 dollars).

[b]Population figure used includes armed forces abroad for years 1917-1919.

Sources:

1902-1906 - 1927-1931: Five year averages of "flow of goods to consumers in 1929 dollars" (from Historical Statistics of the United States, Series F-133, p. 144, original source Simon Kuznets, Capital in the American Economy, Its Formation and Financing, Princeton University Press, Princeton, for National Bureau of Economic Research, 1961), divided by five year averages of population residing in the United States (from Statistical Abstract of the United States, 1962, U.S. Department of Commerce, Washington, D.C., 1962, p. 5), and adjusted to 1954 dollars by dividing by the Department of Commerce 1929 implicit price deflator for personal consumption expenditures, on 1954 base.

1929 - 1960: From Economic Report of the President, 1962, U.S. Government Printing Office, Washington, D.C., 1962, Table B-16, p. 227, adjusted to 1954 dollars (original source: Department of Commerce). Differences in concept between Kuznets' "flow of goods to consumers" and the Department of Commerce's "personal consumption expenditures" make the two series less than precisely comparable.

substantially less than 40 per cent of the preattack value before the feasibility of meeting subsistence consumption requirements would be in doubt.[1]

For several reasons that have been suggested in the earlier discussion, both the assumption and the conclusion are open to question. First, it has been indicated that the relevant consideration in terms of the causes of social unrest may not be the extent to which consumption exceeds physiological minimum levels, but rather the extent to which it falls short of aspiration levels, and they in turn may be strongly influenced by the historical experience of higher standards of living. For example, the level of per capita consumption in the United States in 1933 during the Great Depression was only about 20 per cent below the level of 1929, and above the average level of 1917-1921 (see Table 1). Yet the social protest against the situation of 1933 was pronounced, to say the least. The percentage drop in consumption in the United Kingdom and in Germany in World War II was of similar or lesser magnitude, yet, in spite of the exigencies of the war effort, resistance to a further lowering of living standards was quite strong.[2] Of course, neither the Depression nor World War II had a great deal in common with a potential postattack situation in the United States. In both cases the living standards from which the reduction occurred were much lower than in the United States at present. The social reaction to the Depression was probably influenced by the inequitable distribution of the reduction in living standards, and was obviously the result, not of physical necessity, but of a disease of the economic system. Nevertheless, it is hard to escape the conclusion that the consumption levels in these three

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[1] If per capita GNP fell to 40 per cent of the 1960 level and consumption maintained the same share as preattack, per capita consumption would fall to the 1902-1906 level.

[2] Burton H. Klein, Germany's Economic Preparations for War, Harvard University Press, Cambridge, 1959, pp. 88-89, 213-214 and Table 66, p. 257.

cases would have been much more acceptable if they had been experienced in 1900 rather than in their actual historical setting.

Another reason for caution in using the figures in Table 1 is that the figures on real personal consumption expenditures probably do not adequately measure the relevant concept of real consumption. For example, the figure for 1960 includes a substantial item for transportation to and from work; the corresponding item in 1933 or 1902-1906 would be much smaller. But expenditure on transportation to work is not a luxury item -- at least, not entirely. Given the way our cities are now built, the process that produced a large increase in that expenditure item cannot be reversed. Some items counted as consumption might therefore better be viewed as costs of operating a highly urbanized, industrialized society. Those costs could be reduced, but not entirely escaped, in a postattack economy. The figures in Table 1 therefore somewhat overstate the extent to which real consumption expenditures could be reduced without reducing living standards below the levels of the early twentieth century.

Finally, and most important, the historical levels of per capita real consumption expenditures may be of limited relevance to the postattack subsistence requirement simply because, as discussed previously, the surviving capital stock will not be well suited to providing the mix of consumption items appropriate to a much lower level of total expenditure, and some allowance must be made for this fact. In time, adjustments could be made in the capital stock that would lead to an improvement in the living standard associated with a given value of constant dollar consumption expenditure, but probably not during the reorganization period. On the other hand, living standards would be supported to some extent in the early postattack years by the existence of inventories of durable and semidurable consumption goods in the hands of consumers. The services provided by such goods as clothing, footwear, furniture, and appliances are not included in consumption expenditures; instead, original purchases are included when made. A reduction of expenditure on these items

to zero would affect living standards only as stocks wore out and were not replaced.

During the survival period, real consumption would certainly fall to very low levels, at or below the long run physiological minimum, in many areas of the country. A substantial improvement would occur when order was restored and arrangements were made for distributing the available supplies of consumption goods. It seems reasonable to suppose that the very austere conditions, plus awareness of the grave difficulties the nation was facing, would tend to increase public willingness to accept low levels of consumption early in the reorganization period; that is, low in our sense. But as the shock of war and its immediate aftermath began to wear off, consumption aspirations might rise, coming increasingly under the influence of prewar experience. Thus, intense pressure for higher consumption might appear after reorganization was well under way and life had returned to a semblance of normalcy. The consumption level discussed below might be adopted as a limit at which consumption could and would be held until viability had been achieved and recuperation had begun. If it appeared that this level would result in a failure of the reorganization effort, the limit would presumably be set lower. Since there is no evidence to permit specification of the true subsistence level of consumption, the evidence presented does not bear directly on the question of whether it would be possible to meet subsistence consumption requirements. It does, however, throw some light on the question over a reasonable range of values for the variables involved.

The estimates of consumption requirements presented here were developed by Donald Bear and Paul Clark as part of a study of the relative importance of different industries from the point of view of recovery planning.[1] They assumed a decline in per capita disposable income to 65 per cent of the 1956 level, but this decline would

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[1]D.V.T. Bear and P. G. Clark, "The Importance of Individual Industries for Defense Planning," American Economic Review, May 1961, pp. 460-464 (The RAND Corporation, P-2093, September 1960). See also, by the same authors, "The Importance of Individual Industries for Defense Planning -- Supplemental Data," The RAND Corporation, P-2124, October 1960.

lead to a shift from net saving to dissaving on the part of consumers that would result in per capita personal consumption expenditures being held at 71.5 per cent of the 1956 level.[1] Estimates of post-attack consumption demand were then developed for each sector in the 44 sector input-output table for 1947.[2] These figures were based upon income elasticities of demand estimated from the experience of the years 1929-1940. Table 2 shows the resulting levels of per capita consumption expenditures in the sectors accounting for the bulk of total consumption expenditures, as percentages of the estimated levels in 1956.[3]

To determine the feasibility of holding per capita consumption at or above the indicated levels, it is of interest to know not the direct consumption demand on each sector but rather the total (direct or indirect) demand on each sector that would result if the full list of direct demands on all sectors were met. For example, the figure to compare with an estimate of surviving petroleum refining capacity is not just the direct purchases of petroleum products by consumers, but those purchases plus the petroleum products required to produce and distribute the food and clothing they buy, to generate the

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[1]This would correspond to about 68 per cent of the 1960 level, or about $1122 in 1954 dollars. A comparison with Table 1 shows that this exceeds the 1940 level.

[2]The procedures by which these estimates were made are described by Bear and Clark in The Importance of Individual Industries for Defense Planning -- Supplemental Data, pp. 6-10. The input-output table for 1947 is presented and discussed in W. D. Evans and M. Hoffenberg, "The Interindustry Study for 1947," Review of Economics and Statistics, May 1952, pp. 97-142.

[3]Tables 2 and 3, and other calculations presented in the next few pages, were based upon a breakdown of the preattack and postattack final demand vectors in the Bear-Clark study into consumption and other components. This breakdown was not presented in the two papers cited above. I am indebted to Professor Clark for making this information available. To make the comparisons in Tables 2 and 3, the Bear-Clark postattack consumption figures were divided by .6, thus undoing the allowance they made for the fact that, in the situation they considered, 60 per cent of the population would survive the attack.

Table 2

POSTATTACK CONSUMPTION EXPENDITURES PER CAPITA AS A PERCENTAGE OF PREATTACK, FOR VARIOUS INPUT-OUTPUT SECTORS

Sector number and name	Per cent	Sector number and name	Per cent
1. Agriculture and fisheries	92	11. Products of petroleum and coal	80
2. Food and kindred products	92	13. Leather and leather products	68
3. Tobacco manufactures	80	29. Miscellaneous manufacturing	39
4. Textile mill products	56	30. Coal, gas and electric power	88
5. Apparel	56	31. Railroad transportation	65
7. Furniture and fixtures	40	37. Rentals	80
10. Chemicals	71		

Sources:

D. V. T. Bear and P. G. Clark, The Importance of Individual Industries for Defense Planning -- Supplemental Data, The RAND Corporation, P-2124, October 1960.

W. D. Evans and M. Hoffenberg, "The Interindustry Study for 1947," Review of Economics and Statistics, May 1952, pp. 97-142.

electricity needed in the production of other consumption items, and so on. To obtain an estimate of this quantity, the direct consumption demand on each sector is multiplied by an estimate of the total production of petroleum required to make possible the delivery to consumers of a dollar's worth of the output of that sector, and the totals added. This process has been carried through for some of the sectors for which the total consumption demands thus estimated would very likely be largest in relation to capacity.[1] The results are shown in Table 3, expressed as the percentage of actual 1956 output that would be required to provide the assumed level of per capita consumption for the entire 1956 population.

Ideally, there should be consumption requirement estimates similar to those shown in Table 2 and survival curves like those in Figures 4-10 for the same sectors of the economy, and, of course, with comparable basic data underlying the survival curves and the consumption requirements. The consumption requirement percentages could then be used as the basis for "requirements lines" of the type discussed above, and the levels and patterns of attack could be determined that would make it impossible to meet the assumed consumption requirements for the surviving population. Unfortunately, only in the case of petroleum is there a roughly comparable survival curve and requirement line.[2] In the other cases, it is not possible to

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[1]The appropriate rows of the inverse matrix from the 1947 input-output matrix were the source of the coefficients of total demand on sector i per dollar of final demand on sector j. It should be noted that, in addition to all of the other reasons for caution in interpreting calculations of this sort, the process of multiplying an input-output inverse by a demand vector in which the proportions are drastically different from those of total final demand in the base year can give rise to substantial errors. This is particularly likely when the matrix is as highly aggregated as the one used here, because the observed coefficients may depend heavily on the output mix and therefore on the final demand mix.

[2]Actually, the input-output sector to which this requirement refers is "products of petroleum and coal" (sector 11) which is not the same thing as petroleum refinery products. In effect, therefore, it is assumed that the relations between requirements and capacity that apply to the full input-output sector also apply to petroleum refinery products.

Table 3

PERCENTAGE OF ACTUAL 1956 OUTPUT REQUIRED, DIRECTLY AND INDIRECTLY, TO MEET ASSUMED POSTATTACK CONSUMPTION REQUIREMENTS FOR ENTIRE 1956 POPULATION, FOR VARIOUS INPUT-OUTPUT SECTORS

Sector number and name	Per cent	Sector number and name	Per cent
1. Agriculture and fisheries	72	11. Products of petroleum and coal	47
2. Food and kindred products	79	13. Leather and leather products	68
3. Tobacco manufactures	65	29. Miscellaneous manufacturing	32
4. Textile mill products	43	30. Coal, gas and electric power	37
5. Apparel	54	31. Railroad transportation	41
7. Furniture and fixtures	26	37. Rentals	71
10. Chemicals	39		

Sources:

D. V. T. Bear and P. G. Clark, The Importance of Individual Industries for Defense Planning -- Supplemental Data, The RAND Corporation, P-2124, October 1960.

W. D. Evans and M. Hoffenberg, "The Interindustry Study for 1947," Review of Economics and Statistics, May 1952, pp. 97-142.

consolidate the input-output sectors into the categories survival industry, recovery and military support industry, and so on. Furthermore, the consumption requirements are relatively crude estimates, being based on a rather highly aggregated input-output matrix that was several years old at the time to which the estimates refer.[1] Comparability is further reduced because the population figures underlying the survival curves relate to 1961, the capacity figures to 1957, and the consumption requirements to 1956.

Nevertheless, some general impressions can be derived by comparing the survival curves and the requirements figures. Since both are in percentage terms comparisons tend to be more meaningful than they would otherwise be. In particular, the fact that the underlying data do not all refer to the same date is unlikely to affect the results very much, since the general shapes of the curves describing the geographical distributions of population and industry are not likely to change rapidly. There is probably a general overstatement of the percentages of capacity in various industries that would currently be required to provide the indicated level of per capita consumption for the present population, since some economic growth has occurred since 1956. The results will thus tend to be biased toward the pessimistic side.

A further source of bias is that requirements are expressed as percentages of actual 1956 output, rather than of capacity. Although 1956 was a year of relatively full employment, the gross national product probably could have been greater by perhaps 20 per cent if the economy had been operating "full blast," that is, at levels of capacity utilization and unemployment comparable to those attained

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[1]Bear and Clark made an attempt to allow for possible changes in input-output coefficients, as well as for errors in their estimates of the distribution of final demand among sectors, by a technique that is described in The Importance of Individual Industries for Defense Planning -- Supplemental Data, pp. 9-10.

in 1944.[1] In a postattack situation, the output obtained from a given amount of capacity might well exceed normal levels by 100 per cent or more in industries in which multiple shift operations are not standard practice, maintenance and repair activities could be accomplished in substantially shorter periods of time with more labor, or a substantial fraction of capacity stands idle under normal conditions. Such increases in output could not be accomplished in all industries, since some industries typically operate quite close to the limits of what can be derived from their plant and equipment. But a situation in which viability was in question would presumably be a situation in which the survival of population relative to physical capital was high, and therefore the surviving physical capital could be utilized a good deal more intensively than is usual. Furthermore, the labor supply could be increased in the particular industries where the shortage of physical capital posed the most serious obstacles to viability, at the expense of industries on which the demands of the reorganization effort were small relative to capacity.

The requirements percentages in Table 3 are all less than 80, and, as one would expect, the highest of them are for industries that are largely in the survival industry category. If it is assumed (unrealistically) that all of the component industries of the survival industry aggregate have roughly the same geographical distribution as the aggregate, the curves in Figure 4 can be compared with a requirements line from (0, 0) to (100, 80) in order to determine the range of attacks for which the surviving capacity would be above the requirement _in every industry_. The range extends to attacks on up to 150 of the top population targets, or 30 of the top survival industry targets. If, on the other hand, it is assumed (also unrealistically) that the survival industry aggregate is essentially

[1]This statement assumes an unemployment rate of 1 per cent (as against 1.2 per cent in 1944), and is based on the relations between the unemployment rate and the ratio of actual to potential output presented by Robert M. Solow, "Technical Progress, Capital Formation, and Economic Growth," _American Economic Review_, May 1962, Table 2, p. 82.

homogeneous, then the requirements line should be based on the weighted average of the various requirements percentages. An estimate of this quantity might be 71.5 per cent (postattack per capita consumption expenditures as a percentage of preattack).[1] On this basis, the requirements could be met for essentially the full range of population attacks shown, and for attacks on up to 50 survival industry targets.

Since viability requires that the economy not only satisfy subsistence consumption demands, but also that the fixed requirement be met and depreciation of the capital stock be made good, the use of requirements lines based on consumption demands alone is not strictly justified. A check on the consequences of ignoring these other demands was made by taking the Bear-Clark estimate of government demand as the fixed requirement and a fraction of the estimated investment (construction plus producers' durables) demand as the depreciation component.[2] (The Bear-Clark estimate of investment demand was intended to represent the start of a fairly rapid recuperation, and therefore it presumably exceeds by a considerable margin the amount of gross investment that would be required to make good physical depreciation.) Requirements lines reflecting all three requirements were developed for each of the industries listed in

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[1]It would be an exact estimate if (a) the sectors producing consumption goods or inputs to consumption goods did not contribute to production for any other final demand sector, and (b) the survival industry aggregate were co-extensive with these consumption goods sectors. The fact that (a) is not true means the estimate is biased upward, the fact that the survival industry aggregate is composed of industries that would be cut back less than the average reduction in consumption tends to produce a bias downward.

[2]The industry breakdown of government and investment demands was not presented in the original Bear-Clark study, but the estimates are discussed in The Importance of Individual Industries for Defense Planning, pp. 7-8. The two other final demand categories for which Bear and Clark made estimates -- exports and net change in inventories -- were ignored in deriving the requirements lines. The principal effect of this is to increase the demands on agriculture and fisheries, since Bear and Clark assumed the food inventory would be drawn upon. This assumption would be inappropriate for present purposes.

Table 3, each line showing, for each level of population survival, the percentage of that industry's 1956 output required to meet (1) the fixed government demand, (2) the assumed per capita consumption standards, and (3) a level of investment such that the gross investment share in GNP would be equal to the 1956 ratio of capital consumption allowances to GNP. Each of the requirements lines were then compared with the survival industry survival curves. The conclusions stated above were found to be generally valid, because the industries most affected by the nonconsumption demands were those for which the consumption demands were relatively small. The industry that showed the lowest critical attack levels was food and kindred products; in this case the revised requirements line goes from (0, 2) to (100, 81) instead of from (0, 0) to (100, 79).

Considering all the pessimistic assumptions going into the above comparisons -- including the high (by historical standards) level of per capita consumption taken as a requirement -- it is concluded that whatever problem there is in meeting postattack consumption requirements after an attack directed at population is almost certain to be a problem of the detailed composition of surviving capacity within the aggregate of industries that produce essential consumption goods. In the aggregate, the surviving capacity is likely to be more than adequate, unless more extensive measures are taken to protect the population than was assumed in deriving the survival curves, or the attack is even heavier than the heaviest considered here. The analysis presented above can throw no light on the difficulty of the problem of adapting to inappropriateness in the composition of surviving capacity; this would require a detailed analysis of all of the relevant substitution possibilities, including changes in the mix of consumption goods. The problem probably would not prove to be particularly difficult if the attack were directed at population, for in this case the surviving capacity per capita should be sufficiently far above requirements in the aggregate to make up for inappropriateness in composition. If, on the other hand, the enemy were to attempt to maximize the difficulties of supporting the

surviving population, he would have more attractive options available than an attack on survival industry as an aggregate.

Petroleum provides an example of the difficulties that might be created if special target systems were singled out for attack. The geographical distribution of petroleum refineries is such that an attack on only the top 20 refineries would reduce surviving capacity to about 80 per cent of the amount required to meet the indicated consumption requirement. In view of the particularly crucial role of petroleum in the achievement of viability (as compared with the food processing or apparel industries for example), this is undoubtedly a very important vulnerability of our economy. However, of the total requirement for petroleum of 47 per cent of preattack capacity (for the full population), over 51 per cent is attributable to the demand for petroleum by consumers, while only 16 per cent is accounted for by the demands on agriculture and fisheries, food and kindred products, the transportation sectors, and coal, gas, and electric power. Presumably much more severe cutbacks in direct use of petroleum products by consumers would be possible than are assumed here, and such cutbacks would significantly reduce the total demand. On the other hand, if the total requirement were limited to that accounted for by the sectors listed above, so that it amounted to only $.16 \times 47 = 7.5$ per cent of preattack capacity, an attack on the top 80 petroleum targets would reduce capacity below the requirement.[1]

It should be mentioned that a detailed study of the consequences of an attack on petroleum refineries has been made at the Stanford Research Institute, and the conclusions were somewhat more optimistic than is suggested above.[2] It was found that "threshold of recovery"[3]

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[1]The situation is even worse if nonconsumption demands are reflected in the requirements line. The line then goes from (0, 6) to (100, 57), instead of from (0, 0) to (100, 47).

[2]S. B. Thayer and W. W. Shaner, The Effects of Nuclear Attack on the Petroleum Industry, Stanford Research Institute, Menlo Park, Calif., July 1960.

[3]The "threshold of recovery" requirement is for an amount of fuel "sufficient only to commence recovery." Ibid., p. 3.

requirements for gasoline could be met for a period of about three years, and requirements for distillate[1] for a period of about four years, after an attack that destroyed 100 per cent of the petroleum refineries and left over 85 per cent of the population alive, and this could be accomplished without any rebuilding of refineries and without imports.[2] The following considerations were fundamental in arriving at this somewhat remarkable conclusion. First, with respect to gasoline, it was found that natural gasoline plants capable of producing an amount of usable motor gasoline equal to 7 per cent of the preattack gasoline supply would survive the attack.[3] More importantly, the "threshold of recovery" requirements for the first postattack year amount to only 6 per cent of preattack consumption in the case of gasoline, and .76 per cent in the case of distillate. In the latter case, it is found that no production would be possible, but stocks equal to 6.3 per cent of preattack annual consumption would survive the attack. Requirements are estimated at 1.8 per cent of preattack consumption for the years following the first; thus $3 \times 1.8 + .76 = 6.16$, and the surviving stocks would meet requirements for something over four years.[4]

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[1]The category "distillate" includes kerosene, jet fuel, heating oils, and diesel fuel.

[2]*Ibid.*, p. 118, and supporting tables. The statement is made that surviving stocks and first year production of distillate exceed first year requirements by 88 per cent after the refinery attack. This appears to be an error, inasmuch as it is inconsistent both with the supporting tables and with the statement that stocks would be depleted in about four years. Actually, availabilities exceed requirements after one year by 723 per cent. The situation is further confused by a misprint in Table 2, p. 9, which makes it appear that requirements exceed availabilities.

[3]*Ibid.*, p. 15. It should be noted that the conclusion that the quality of the gasoline obtained from this source would be adequate is dependent on an assumption that the four tetraethyl lead plants in the United States would not be included in the target list (*ibid.*, p. 66). Although the natural gasoline plants are too numerous and dispersed to be a reasonable addition to the refinery attack, the same obviously cannot be said for the tetraethyl lead plants.

[4]*Ibid.*, Table 6, p. 29, Figure 9, p. 38, and Table 38, pp. B-29 through B-30.

It seems reasonable to suppose that these "threshold of recovery" requirements are somewhat too austere to be realistic. For example, no allowance is made for heating oil as a use of distillate, which accounted for roughly 50 per cent of preattack distillate consumption.[1] The requirements for diesel fuel by the railroads are estimated at 3.6 per cent of preattack use by the railroads.[2] No allowance is made for use of gasoline or diesel fuel to transport workers to and from work, and no allowance is made for gasoline or diesel fuel used in truck transportation.[3]

If these "threshold or recovery" requirements have any realistic interpretation at all, it is that these levels of consumption of gasoline and distillate might possibly suffice to keep the economy in cold storage, as it were. The part of the population not employed in agriculture or in the minimal operation of the railroads would spend its time walking to the food distribution points and back. It seems quite likely that these requirements are greatly below what would be required in order to achieve viability. In particular, it seems unlikely that the assumed levels of fuel consumption would support the amount of economic activity involved in rebuilding significant petroleum refinery capacity in three or four years. Thus, on the assumptions made, the self dependence of petroleum would become manifest, and the effort to achieve viability would fail.

In view of the particular importance of food as a component of subsistence consumption, the question of what changes in the nation's diet might be made in response to postattack shortages will now be examined briefly. Tables 4 and 5 provide an historical perspective on this question. Table 4 shows the changes that have occurred since 1910 in per capita civilian consumption of some important foods. The general rise in consumption standards, associated with rising per

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[1] _Ibid._, Figure 9, p. 38.

[2] _Ibid._, Figure 9, p. 38, and Table 38, pp. B-29 through B-30.

[3] The uses that _are_ allowed for are listed on p. 3, _ibid._

TABLE 4

APPARENT PER CAPITA CONSUMPTION OF VARIOUS FOOD COMMODITIES IN THE UNITED STATES, 1910-1960

(in pounds, except eggs)

Item	1910	1930	1940	1960	Min (year)	Min ÷ 1960 (per cent)	Max (year)	Max ÷ 1960 (per cent)
Meats[a]	146.4	129.0	142.4	161.4	117.4 ('35)	72.7		
Edible fats and oils[b]	na	na	46.4	45.4	39.1 ('45)	86.1		
Butter[c]	18.3	17.6	17.0	7.5	7.5 ('60)	100.0		
Fruits (total)[d]	158.8	170.8	203.7	200.2	151.9 ('21)	75.9		
Fresh fruits	137.9	133.6	142.1	97.5	97.1 ('58)	99.6		
Vegetables and melons, total[d]	na	195.7	206.4	231.5	139.8 ('19)	60.4		
Fresh vegetables and melons	na	144.9	143.4	131.7	101.4 ('19)	77.0		
Potatoes	198	132	123	102	99 ('56)	97.1	198 ('10)	194.1
Dairy products[e]	759	819	819	653	653 ('60)	100.0		
Eggs[f]	306	331	319	334	280 ('35)	83.8		
Chickens and turkeys[g]	15.5	17.2	17.0	34.4	13.3 ('17)			
Sugar, refined	75.4	109.6	95.7	98.9	73.9 ('45)	74.7		
Wheat flour	214	171	155	118	118 ('60)	100.0	214 ('10)	181.4
Corn flour and meal	51.1	28.3	21.8	7.4	7.4 ('60)	100.0	51.1 ('10)	690.5

Notes:

na indicates not available. [a]Carcass weight. [b]Total fat content. [c]Actual weight. [d]Farm weight equivalent.

[e]Whole milk equivalent, fat-solids basis. [f]Number of eggs. [g]Ready-to-cook.

Sources:

National Food Situation, U.S. Department of Agriculture, Economic Research Service, May 1962, Table 3, p. 4. Historical Statistics of the United States, U.S. Department of Commerce, Series G 552-584, pp. 186-187. Consumption of Food in the United States, 1909-52, September 1953, pp. 116-121, and Supplement for 1961, September 1962, pp. 17, 22-24, 28, U.S. Department of Agriculture, Bureau of Agricultural Economics.

TABLE 5

PER CAPITA CIVILIAN SUPPLIES OF PRINCIPAL FOODS IN THE UNITED KINGDOM, PREWAR AND 1944

(in pounds)

Item	Prewar	1944	Per cent change prewar to 1944
Dairy products, excluding butter[a]	38.3	49.0	27.9
Meat (including canned meat, bacon and ham)[b]	109.6	96.1	-12.3
Fish, poultry and game[b]	32.8	23.5	-28.4
Eggs and egg products[c]	24.0	23.2	-3.3
Oils and fats (visible)[d]	45.3	39.0	-13.9
Sugar and syrups[e]	109.9	75.7	-31.1
Potatoes	176.0	274.6	56.0
Fruit (including tomatoes)[b]	141.4	93.6	-33.8
Pulses and nuts	9.6	6.8	-29.2
Vegetables	107.5	124.8	16.1
Grain products	210.1	252.8	20.3
Tea, coffee, and cocoa	14.7	12.8	-12.9

Notes:

[a]Total milk solids.

[b]Edible weight.

[c]Pounds of fresh egg equivalent.

[d]Fat content.

[e]Sugar content.

[f]Fresh fruit equivalent.

Source:

R.J. Hammond, Food, Volume I: The Growth of Policy, H.M. Stationery Office, London, 1951.

capita income, is reflected in the substantial increase in per capita consumption of meats, poultry, and eggs, and a decrease in consumption of grains and potatoes. In view of the high vulnerability of livestock to fallout and the predominance of grains in the nation's food inventory, a reversal of this historical improvement would be likely in a postattack situation. Further modifications in the average postattack diet might be made in order to reduce the intake of long lived radioisotopes, particularly Strontium 90. This consideration would lead to a relative decrease in consumption of high calcium foods such as leafy vegetables and dairy products, and a relative increase in consumption of apples and potatoes.

The "Min" column of Table 4 shows the lowest level that per capita consumption of each of the various foods reached in any year in the period 1910 to 1960 inclusive.[1] An indication is provided of the size of the reductions that might be made in the consumption of particular items without going beyond the limits of national experience since 1910. A reduction in consumption of <u>all</u> foods to "Min" levels would result in an average diet worse than anything that has been experienced since 1910, and might well bring the diet below long run physiological minimum standards. Increases in some items would have to be made to offset decreases in others; in particular, increased consumption of grains and potatoes would be likely. The "Max" column shows the maximum per capita consumption of these items that has occurred since 1910.

Table 4 indicates that quite a large adjustment of the average diet in the "bread and potatoes" direction would be possible without going much beyond the limits of experience since 1910. It is interesting to note that the 1910 diet itself is only moderately superior to a diet consisting of "Max" amounts of grains and potatoes and "Min" amounts of everything else, with meats and chicken and turkey showing the largest differences. The historical decline in the consumption of corn flour and meal is also of some interest, in view of the importance of corn in the food stockpile.

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[1]Except in the cases of fats and oils, and vegetables, where the "Min" values are the lowest since 1931 and 1919, respectively.

Since the United States has always been relatively well fed in comparison with other nations, historical experience in the United States may be an unsatisfactory guide to subsistence levels of food consumption, if physiological subsistence is relevant at all. Some evidence in this direction is shown in Table 5, which compares per capita consumption of various food items in the United Kingdom prewar and in 1944. Where figures can be derived comparable with those in Table 4, it appears that the British wartime diet was significantly inferior to the U.S. diet in 1910, especially in meats, eggs, and poultry. Since even the British wartime diet was unsatisfactory mainly in comparison with what had been attained earlier, rather than in absolute terms, it would appear that the United States diet of 1910 could be regarded as well above a subsistence level. However, this conclusion must be qualified by noting the possible importance of previous experience of a high living standard as a determinant of the level of consumption that would suffice to prevent the appearance of various forms of social unrest.

Inventories

It has been noted previously that the composition and geographical distribution of the surviving resources in (or potentially in) the subsistence loop determine the schedule the economy must meet if the reorganization effort is to succeed. Not only are inventories of finished subsistence goods involved, but also goods in process and stocks of inputs -- petroleum, farm machinery, and so forth. This brief quantitative discussion presents only a gross view of the problem, in the spirit of the aggregative analysis of Section III. Only food inventories are considered, and in the forms in which they happen to exist, and only brief reference is made to the problem of converting the inventories into a more usable form by processing and distribution.

Several studies have been made of potential postattack food supplies.[1] In general, the conclusion is that under plausible assumptions as to the level and pattern of attack, U.S. civil defense preparations, and so forth, the surviving food supplies in the nation as a whole would almost certainly be adequate to sustain the surviving population for a period of two years or more. That is, considerations of palatability aside, it would not be absolutely necessary to resume food production during the first two years after the war. This conclusion is subject to some qualification in that, without some special preparations or a limited resumption of production, the nutritive balance of the diet might be such as to lead to some deterioration in the health of the population.[2] Furthermore, it should be noted that the standard of adequacy is physical survival rather than subsistence in our sense.

Even when suitably qualified, the fact that there would be more than a two year supply of food is probably the single most important consideration that underlies an optimistic assessment of the prospects for reorganization. Without that substantial buffer against shortages of a critical component of subsistence consumption, the inescapable uncertainties in any estimate of when production might be resumed would appear to be overwhelming. If, for example, it appeared that achievement of viability would be contingent upon avoiding more than a 50 per cent reduction in agricultural output in the first postattack year, very extensive preattack plans and preparations would be required to assure success, if such assurance is attainable at all. But the size

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[1] Including unpublished work done at RAND by T. A. Marschak and J. M. Carrier, and the following studies done at the Stanford Research Institute: Paul D. Marr, Food Supply and Production Following a Massive Nuclear Attack, October 1958; and Attack Damage Digest (U), December 1959 (Secret-Restricted Data).

[2] In general it appears that, given the character of the existing food inventories, the food energy (number of calories) they contain is a reasonably good basis for determining how long they will support the population; deficiencies in other nutrients would either be small or readily eliminated by a small amount of additional stockpiling.

of the food stockpile obviates the necessity of assessing the feasibility of performing complicated feats of institutional and economic recovery in short periods of time.

Table 6 presents some figures on U.S. food stocks in 1960: the average and minimum end-of-quarter stocks of some important food items, the percentages of average stocks owned by the Commodity Credit Corporation, the percentages stored on farms, and the number of calories of food energy contained in the stocks (calculated on the basis of the calories remaining after conversion to edible or usable form, for example, wheat to wheat flour). Food losses and destruction of food energy values in food preparation and use are not allowed for. The total food energy in the average stocks of the commodities listed is 443.4 trillion calories. Allowing 3000 calories per person per day (a reasonable value on the same basis of evaluation as was applied to the stocks), this would support the entire 1960 population of about 180 million for 2-1/4 years. However, 58 per cent of the total food energy in the listed items was in the corn stocks. Use of the entire corn stockpile for human consumption in the form of corn meal and flour over a period of 2-1/4 years, would imply a level of per capita consumption of these items several times higher than the 1910 level. That level was itself about six times the present level (see Table 4). If both the wheat stockpile and the corn stockpile were used over a period of 2-1/4 years, the per capita consumption of the two combined would be roughly twice the 1910 level. Except under very austere conditions, much of the corn would undoubtedly be allocated to its typical use of food for livestock, at a substantial loss in food energy obtained, but with a substantial beneficial effect on the quality of the diet. Considering that the stocks listed above by no means account for the entire U.S. inventory of storable foods (no canned goods are included, for example), food supplies should still be adequate for at least two years, if necessary, in spite of the fact that wheat and corn account for such a large proportion of the food energy value.

Thus far, no allowance has been made for the possibility that the population might survive a nuclear attack in larger proportion

Table 6

AVERAGE AND MINIMUM LEVELS OF STOCKS OF VARIOUS FOOD COMMODITIES -- 1960

Item[a]	Average[b]	Minimum[b]	CCC divided by average (per cent)[c]	Average on farms (per cent)[d]	Calories[e]	Average Calories (trillions)	Minimum calories (trillions)
Wheat	1,822	1,314	65.6	17.5	88,860	161.9	116.8
Wheat flour	444	416					
Corn	3,090	1,789	37.5	55.3	82,900	256.2	148.3
Barley	311.1	168.0	22.8	53.6	42,768	13.3	7.2
Oats	672	268	2.2	88.5	9,759	6.6	2.6
Rice	945	271	69.7		1,593	1.6	.4
Rye	21.6	10.5	24.6		73,360	1.6	.8
Butter	106.5	33.9	98.9		3,327	.4	.1
Cheese	316.8	261.8	2.4		1,784	.6	.5
Milk, dried	520	407	70.1		2,249	1.2	.9

Notes:

[a] Wheat, corn, barley, oats, and rye are in millions of bushels. All others are in millions of pounds.

[b] Refer to average and minimum of end-of-quarter levels of stocks, except for rice, butter, cheese, and dried milk. For rice, butter, and cheese, the figures are the average and the minimum of the end-of-month stock levels. For dried milk, the figures are the average and minimum of end-of-month stocks in manufacturer's hands, plus the June 30 holdings of the Commodity Credit Corporation.

[c] Stocks owned by Commodity Credit Corporation as of June 30, as a percentage of average stocks.

[d] Average end-of-quarter stocks on farms as a percentage of average total stocks.

[e] Wheat, corn, barley, oats, and rye -- per bushel; all others per pound.

Sources:

For levels of stocks other than CCC holdings, Survey of Current Business, March 1961, pp. S-26 to S-28. For CCC holdings, Statistical Abstract of the United States, 82nd edition, Washington, D.C., 1961, p. 633. For calorie contents of foods, Tables of Food Composition, U.S. Department of Agriculture, Washington, D.C., 1950.

than food inventories, in which case the postattack food supply problem would be more serious than estimates based on preattack inventories and population suggest. However, detailed damage assessment of plausible attacks indicates that the probable result is heavier attacks leading to higher and higher levels of survival of the food inventory in relation to population. The food products industry is not highly concentrated geographically; retail food stores are distributed with the population; stocks on farms and those owned by the CCC would be barely touched by most attacks. It should be noted that food that does not come in direct contact with fallout debris is not made inedible by fallout, and even when direct contact occurs it may be salvaged by washing and/or disposal of the outer portions.[1]

That is, of course, one component of subsistence consumption that is even more important than food -- water.[2] It is necessary to distinguish the short run threat of death from thirst, or from radiation sickness, from the long run threat from continued ingestion of water supplies contaminated with long lived radioisotopes. The threat of death from thirst need not be of first order importance in areas affected only by fallout, provided, of course, that steps are taken to assure that service from normal water supply systems is not interrupted for more than a week or two. If fallout shelters are

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[1]It appears that the only situations in which fallout contamination might render a large fraction of a given stock of food inedible would be situations in which the food was (a) unsheltered, and either unpackaged or packaged in containers that would admit fallout particles (for example, burlap sacks), and (b) of a type that would make washing and/or removal of outer portions infeasible or ineffective (for example, flour, dried fruits, oily seeds), and (c) spread out in a relatively thin layer, so that disposal of the outer portions would involve disposing of most of the stock. It hardly seems probable that these conditions would apply to a significant amount of food supplies, except, of course, those still in the fields. However, it is extremely important to note that only on the assumption of well informed and careful behavior does this imply that contamination of food supplies will not represent a significant threat to survival.

[2]Most of the technical conclusions in this and the following two paragraphs are based on Eric T. Clarke, et al., The Potential Radiation Hazard from Water Supplies and Milk After a Nuclear Attack, Technical Operations, Inc., Report No. TO-B 60-27, November 1960.

stocked with a supply of uncontaminated water (or other fluids) adequate for the first two weeks, the use of normal water supplies thereafter would not involve a major health hazard in most areas (by postattack standards). In areas of heavy fallout, where water is drawn from shallow reservoirs, and where normal water treatment methods do not include coagulation and filtration, it should be a relatively simple matter to develop emergency measures that would remove the hazard. For example, a few home water softeners in the neighborhood, an industrial plant that uses ion exchange methods to obtain soft water, or a good underground water source would solve the problem.[1] It is important to note that the use of water for drinking accounts for a very minor share of total water use even in the home, let alone in a city where there are major industrial users of water. The use of water for purposes other than drinking would involve few hazards;[2] and it would not be as difficult to obtain uncontaminated or decontaminated water for drinking as it would be to decontaminate the entire water supply.

In areas served by water supply systems that suffered significant blast damage, the problems would be a good deal more serious. It is not clear to what extent the network character of water supply systems would result in interruption of water supplies in areas where the blast effects would not be lethal to an unprotected population. It is eminently clear, however, that a serious problem of distributing water to survivors would arise if the population were

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[1] Clarke, et al. (pp. 25-26) cite results indicating that substantial benefits might be derived from a preparedness measure that would involve supplying the population with pills containing sufficient inert iodine to saturate the thyroid. Such pills, if taken before beginning to drink contaminated water, will greatly reduce absorption of radioactive iodine by the thyroid, which is a major component of the short term threat.

[2] Except, perhaps, that in the early time period contaminated water might not be very useful for removing contamination from food. Also, it may be that some industrial processes (including water purification) tend to concentrate radioactivity to an extent that some precautions would have to be taken.

reasonably well protected against blast. Solution of this problem would certainly require preattack planning and preparations.

Contamination of water supplies by Strontium 90 and other long lived isotopes would have a significant effect on the health of the population if nothing were done to deal with the problem. However, it seems clear that the kinds of emergency measures mentioned above -- drinking water from underground sources, or water treated by ion exchange methods -- could be gradually replaced in the course of the reorganization period by more systematic arrangements for distributing bottled drinking water, leaving normal water supply systems to meet the other needs. Supplies of uncontaminated water could probably be obtained by using large scale ion exchange equipment (such as is used in some generating plants to obtain demineralized cooling water), or perhaps even by distillation.[1]

RESUMPTION OF AGRICULTURAL PRODUCTION

Although possession of a large food inventory in relation to the surviving population is conducive to success in achieving viability, it obviously does not guarantee success. Since subsistence consumption may be expected to account for a large proportion of the total output required for viability, and since food accounts for the largest share of subsistence consumption, the question of whether food production will recover adequately by the time inventories are exhausted is at the center of the entire viability problem. The discussion below specifically treats the problems of postattack agriculture, which would probably be of greater magnitude than those of food processing and distribution. These problems are of two main types. First, there is the outright destruction of economic resources needed in agricultural production -- livestock, farm manpower, petroleum refineries,

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[1]It should be emphasized that the long term health hazards, however serious by peacetime standards, are of little consequence in comparison with the immediate consequences of the war and the threat of a failure to achieve economic viability. Thus the types of measures described here could and would be postponed or dispensed with if they competed very seriously with the reorganization effort.

fertilizer plants, and so forth. Second, there are the relatively long term effects of the war on the natural environment, including the radioactive contamination of the soil; effects of fires in forests and grasslands; disturbances in the ecological balance among various species as a result both of fire and of differential sensitivity and exposure to radiation; and others. This second category of effects is a distinctive feature of the problem of agricultural production in that the standard preparedness measures of stockpiling inputs and "hardening" capacity are not applicable. One cannot stockpile the natural environment or move farms underground, although it is possible to stockpile supplies or "harden" capacity that will facilitate control of the natural environment.

Of the effects in the second category, the best understood is probably the contamination of the soil. The primary focus of concern has been on contamination by the radioisotope Strontium 90, which is particularly dangerous because of its chemical similarity to calcium and its consequent bone-seeking properties, and because growing plants take it up from the soil in large amounts. The problem of decontaminating soil has been investigated, but the methods developed thus far do not appear to be very practical if decontamination of large amounts of cropland is required. The most effective seems to be the removal and burial of the top few inches to top soil in which most of the fallout remains for a substantial period of time.[1] A huge investment of time and effort would obviously be required if this method were to be applied to a significant fraction of the

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[1]The effectiveness of several methods of decontaminating soil is discussed in the testimony of Dr. H. H. Mitchell, in Civil Defense, 1961, Hearings before a subcommittee of the Committee on Government Operations of the House of Representatives, 87th Cong., 1st Sess., August 1961, pp. 341-342. See also the testimony of Dr. R. F. Reitemeier and discussion in Biological and Environmental Effects of Nuclear War, Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, 86th Cong., 1st Sess., June 1959, pp. 784-791.

roughly 450 million acres of total cropland in the United States. It seems doubtful that such an effort could be successful in time to make a significant contribution to the expansion of agricultural output in the first three or four years, especially since fuel, which might be in short supply, would be needed for tractors and earthmoving equipment. Furthermore, the loss of the fertile top soil could turn out to be almost as serious a long run problem as the contamination.

Unless more effective decontamination methods are developed, the agricultural land available in the early postattack years will probably consist almost entirely of land that escaped high levels of contamination in the first place. A recent study by O. E. Williamson and K. D. Moll of the Stanford Research Institute[1] indicates that attacks in the neighborhood of 20,000 megatons might reduce cropland available in the first postattack year to 10 to 40 per cent of that available preattack, depending on the attack and the cutoff radiation tolerance chosen. (See Table 7.) If land covered by an H + 1 radiation intensity of 300 roentgens per hour is considered unavailable for food production, a 23,000 MT attack on military and population targets would reduce available cropland to about 13 per cent of the preattack level. If the cutoff radiation level is raised to 1000 r/hr at H + 1, the availability is raised to 27 per cent. Williamson and Moll state that the latter standard is probably more reasonable for production in the first postattack year, under extreme conditions.[2] For an attack of 1500 megatons on military and population targets, which is a more reasonable approximation to the threat in the next few years, cropland availability would be 73 per cent of preattack for the lower radiation tolerance level and 86 per cent at the higher.

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[1] O. E. Williamson and K. D. Moll, Postattack Farm Problems, Part II: Attack Effects on Inputs and Farm Output, Stanford Research Institute, October 1961.

[2] Ibid., pp. 28-29.

Several points should be noted in interpreting the figures in Table 7: such massive attacks as are considered in the Stanford Research Institute study would result in very high population casualties even if reasonably good fallout shelters were available for the population. In the 23,000 MT attack (4000 megatons in the largest attack directed at population centers), 60 per cent of the population would be killed. The per capita availability of cropland, under the 1000 r/hr availability standard, would therefore be substantially in excess of 50 per cent of normal. Indeed, the study concludes, after considering all major agricultural inputs and several adaptations of agricultural practices to postattack conditions, that per capita agricultural production in the first postattack year would not be less than about 60 per cent of normal in the worst[1] case considered.[2]

The question of what the appropriate cutoff radiation tolerance should be is not one that can be answered independently of a total assessment of postattack conditions and the requirements for viability. Since the main concern is with the increased incidence of bone cancer, possibly leukemia, that would result from contamination of the national diet with large amounts of Strontium 90, the problem is not likely to involve an immediate threat to the survival of a significant fraction of the population. Even an increase in the incidence of bone cancer and leukemia of two orders of magnitude would be far from constituting such a threat (under present conditions it would increase the

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[1] Ibid., p. 209. ("Worst" means "worst from the point of view of agricultural production per capita.")

[2] Given the size of the food inventory, this would of course be more than adequate. However, the SRI report makes clear that maintaining or increasing this level of production in subsequent years would be possible only if the work of reconstructing major industries on which agriculture depends progresses at an adequate pace. The first year estimates do not reflect the full impact of the war on industries because it is assumed that inventories are being drawn upon, and, in such cases as fertilizers and pesticides, the effects of reducing an input in one year sometimes continue into subsequent years. Thus the SRI study is not, and does not purport to be, a proof of the feasibility of reorganization in our sense.

Table 7

FALLOUT COVERAGE OF CROPLAND AND CATTLE UNDER FOUR ATTACK CONDITIONS

(per cent exposed)

Fallout (r/hr at H+1 hr) greater than:	Cropland[b]				Cattle (including dairy)[c]			
	400 MT Mil[a]	1,500 MT Mil-Pop[a]	19,000 MT Mil	23,000 MT Mil-Pop	400 MT Mil	1,500 MT Mil-Pop	19,000 MT Mil	23,000 MT Mil-Pop
100	20	44	81	91	20	46	75	88
300	9	27	74	87	9	28	69	84
1,000	4	14	59	73	4	15	54	70
3,000	2	7	12	29	2	7	24	39

Notes:

[a] "Mil" indicates military targets only are attacked, "Mil-Pop" indicates military and population targets attacked. Attack weights are given in megatons.

[b] In terms of harvested acres in 1954.

[c] In terms of number in 1954.

Source:

O. E. Williamson and K. D. Moll, Postattack Farm Problems, Part II: Attack Effects on Inputs and Farm Output, Stanford Research Institute, 1961, Table 1, p. 33.

over-all death rate by about 60 per cent), and such a result is improbable even as a consequence of a war in the 20,000 megaton range.[1] Hence, it can plausibly be argued that contamination of cropland with Strontium 90 would be of quite minor significance as compared with the immediate threat of a failure to achieve economic viability. Contamination of the food supply would be accepted to the extent required by the reorganization effort, since eating contaminated food would clearly be preferable to starvation.

The significance of any particular level of postattack availability of cropland must be examined in relation to all possible measures that might be taken to adjust to the situation. One of the most obvious adjustments would be to produce the items for which the contamination problem is most serious -- milk and vegetables -- on the least contaminated land, food crops with lower Strontium uptake on more contaminated land, and nonfood crops and livestock on the most contaminated land.[2] Also, if agricultural inputs other than land are available in adequate amounts, the uncontaminated land might be farmed very intensively. In fact, if the available cropland were farmed with the best preattack agricultural technology (instead of with the average technology), the larger output per acre harvested would probably more than compensate for the acreage lost. Finally, steps might be taken to assure that the least contaminated food went to those groups in the population most susceptible to the damaging effects of Strontium 90 -- children and pregnant women.[3] This would substantially reduce

[1]That is, the internal dose from eating contaminated food would not produce these results. It should be noted that the external gamma dose sustained by survivors is likely to be a more important factor in increased incidence of bone cancer and leukemia than the Strontium 90 problem.

[2]It is advantageous to raise livestock on the relatively more contaminated land because the concentration of radioactivity in the meat is much less than in an animal's feed.

[3]A scheme for accomplishing this by establishing different grades of food, according to contamination, has been suggested by Kahn, pp. 66-67.

the public health problems produced by any given level of contamination. Unfortunately, quantitative estimates of the combined results of all of these measures of alleviation are not available.[1]

Given the present state of knowledge and the currently planned civil defense program, the question of how serious the Strontium 90 problem would be after a war in which 20,000 megatons were detonated in the United States is actually quite academic. Without much more elaborate preparations than are now being considered, it is believed that an attack of that magnitude would make viability impossible. Even if elaborate preparations were made, the outcome would still be uncertain.

Another major category of effects that a thermonuclear war would produce on the natural environment includes the various effects of mass fires. It is a matter of some dispute whether the area that would burn as a result of a medium-sized thermonuclear war would be so large as to alter the natural environment in a large fraction of the nation's area, to the extent that major difficulties would be created for postattack agriculture. In testimony before the Joint Committee on Atomic Energy, in 1959, Dr. John N. Wolfe presented a picture of the consequences of an attack on the United States of 1,446 megatons that would seem to imply that the adverse effects on

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[1]Not enough is known of the consequences of accepting various levels of Strontium 90 contamination and the potential effectiveness of various measures of alleviation, under a range of situations. Although the contamination of land is not of central importance when the problem under consideration is the achievement of viability, it may well be of central importance from the point of view of estimating economic recuperation time, and is certainly of great, if not central, importance in assessing the long run costs of the war. The reason that contamination may be of central importance in the recuperation context is that, by devoting more resources to carrying out adjustments such as intensive farming of uncontamined land, the nation would be able to reduce the health hazard from Strontium 90, but at the expense of having less resources available for the recuperation effort. An adequate study of the problem would involve considering the health hazard from various levels of contamination, the adjustments that could be made in diets and in farming practices, and the resources required to carry out the adjustments, on various assumptions as to the weight of attack.

postattack agriculture would be very serious.[1] On the other hand, more recent testimony before the Military Operations Subcommittee[2] suggests that the effects from an attack of that general magnitude might be approximately the same as the combined effects of the forest fires that occurred in the United States in the years 1930 and 1931,[3] which would imply that the effects on agriculture would certainly not be overwhelming. The discussion below contains no original estimates of the magnitude of the problem, but the factors involved and the extent of the uncertainties are summarized.

Figure 11 shows the slant ranges to which various amounts of thermal energy are delivered for weapon yields between 1 MT and 100 MT, for two visibility conditions. Table 8 translates the three levels of thermal energy shown into effects on man and on some common materials. The line with the steeper slope[4] in Fig. 11 shows the radii equivalent to the minimum areas of fire spread from weapons of various sizes, as estimated by the U.S. Forest Service.[5] These minimum areas of firespread apparently assume little or no spread beyond the area where primary ignitions occur, as is suggested in Fig. 11

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[1] U.S. Congress Joint Committee on Atomic Energy, Biological and Environmental Effects of Nuclear War, pp. 832-842.

[2] U.S. Congress, Civil Defense -- 1961, testimony of Dr. J. E. Hill, pp. 344-360.

[3] Ibid., p. 357.

[4] The reason for the steeper slope is that the thermal energy from a weapon of larger yield is emitted over a longer period of time, hence the effect produced in any material exposed to that energy is smaller (because there is time for the energy to be carried away), and hence a larger amount of thermal energy is required to ignite the material.

[5] This line was fitted to the figures for one, three, and ten megatons given in Dr. Hill's testimony (ibid., Table H-4, p. 356), after converting the minimum areas burned to equivalent radii on the assumption that the area is a circle. These minimum areas of fire spread apparently assume that only the area of primary ignition burns, hence the assumption of a circular area is reasonable. The original study done for the Forest Service was by W. S. Jewell and A. B. Willoughby, A Study to Analyze and Improve Procedures for Fire Damage Assessment Following Nuclear Attack, Broadview Research Corporation, Burlingame, California, October 1960.

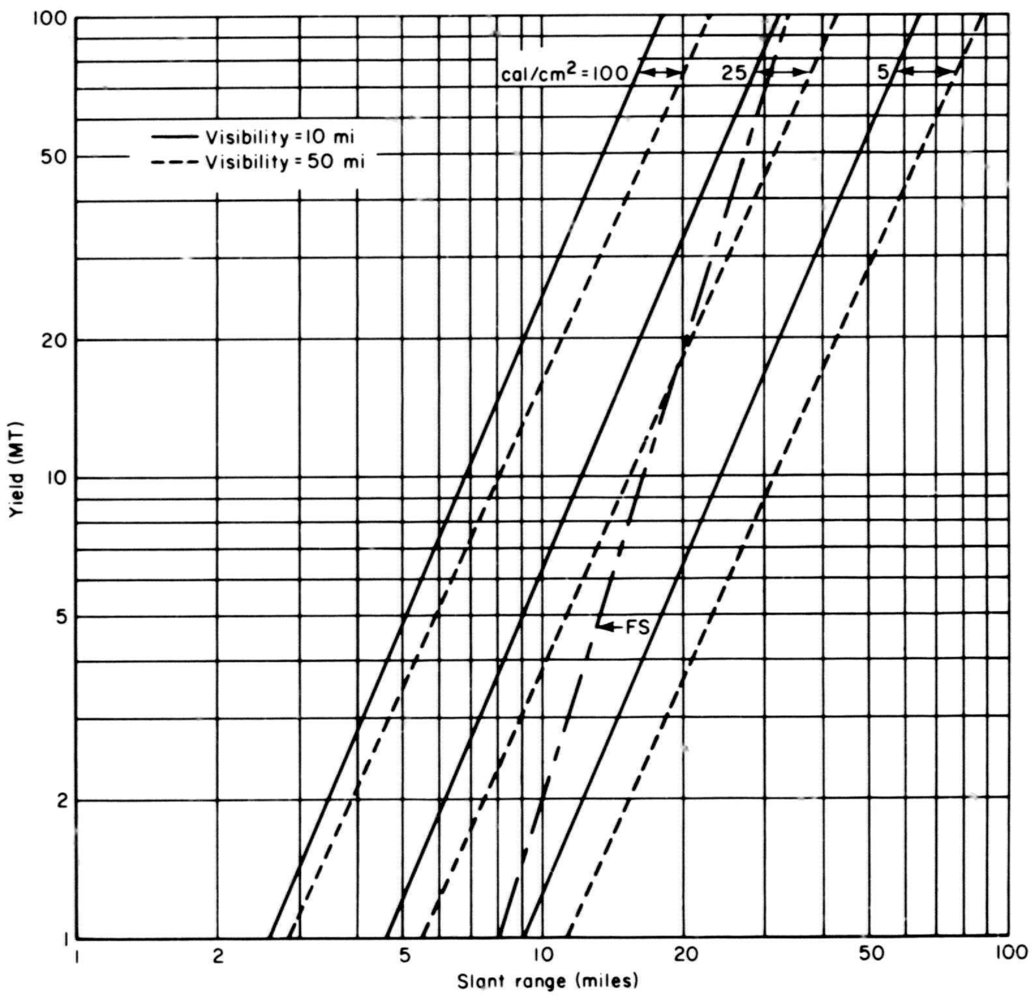

Fig. 11 — Slant ranges to which various thermal energies extend
(Air burst at low altitude)

Source:

Based on Samuel Glasstone (ed.), The Effects of Nuclear Weapons, revised edition, U.S. Atomic Energy Commission, Washington, April 1962, equation 7.103.2 and Figure 7.104, pp. 361-362. The lines above were fitted to points derived in part from an extrapolation of the data in Figure 7.104, and are less reliable for distances in excess of half the visibility range.

Table 8

EFFECTS OF RADIANT EXPOSURES OF 5, 25, AND 100 CAL/CM^2
(for 10 MT weapon)[a]

Radiant Exposure	Effects[b]
5 cal/cm^2	At least first degree burns, ignites dark colored rayon cloth, newspaper
25 cal/cm^2	Severe third degree burns, ignites light colored rayon cloth, auto seat covers, burlap, paper cartons, pine needles, grass, rotted wood
100 cal/cm^2	Melts common plastics such as plexiglass, polyethylene, bakelite

Notes:

[a]For relevance of weapon yield, see note 2, p. 128.

[b]Lower exposures will produce some of the effects listed.

Source:

Samuel Glasstone (ed.), The Effects of Nuclear Weapons, revised edition, U.S. Atomic Energy Commission, Washington, D.C., April 1962, pp. 328-334 and 564-572.

by the range of thermal energies delivered to the distances indicated by the line FS. The same Forest Service study also presents maximum areas of firespread; these are supposed to indicate the probable extent of firespread for the regions of the country and times of year in which conditions are most favorable to firespread.[1] These areas tend to be less dependent on the yield of the weapons involved, as one would expect. The range given is from 8,280 square miles for a 1 MT weapon to almost 10,000 square miles for a 10 MT weapon.

It is of some interest to use these figures as the basis for an estimate of the total area that would be burned over as a result of the 1,446 megaton attack analyzed in the 1959 hearings before the Joint Committee on Atomic Energy. The minimum estimates yield a value of about 138,000 square miles, compared with a total of 162,000 square miles burned over by the forest fires of 1930 and 1931.[2] The maximum estimates, on the other hand, yield a value of about 2,406,000 square miles -- 81 per cent of the land area of the conterminous United States, compared with 4.6 per cent for the minimum estimates.[3] It is certain, as will be indicated below, that this high estimate is far too high, and the low estimate is probably much more accurate. Thus, simple calculations do not demonstrate that fire would be a negligible problem; nor do they show that fire would <u>necessarily</u> create significant problems. The range of uncertainty brackets the range of interest.

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[1] These figures are also available in Dr. Hill's testimony in U.S. Congress, <u>Civil Defense -- 1961</u>, p. 356.

[2] <u>Ibid</u>., p. 353.

[3] The minimum figures were obtained by assuming that each weapon in the attack would result in the burning of an area equal to that of a circle with radius given by the FS line in Fig. 11, for a weapon of that yield. Similarly, the maximum figures were arrived at by assigning to each weapon an area obtained by interpolation, where necessary, from data in Dr. Hill's testimony. <u>Ibid</u>., p. 356. No allowance, therefore, has been made for the fact that the primary ignition areas of some of the weapons would overlap.

Efforts to pin down the probable extent of the burned area in the event of a thermonuclear war are handicapped by the number and complexity of the factors known to be involved, and by the complete absence of any actual experience with mass fires started by a weapon in the megaton range. The extent of fire damage is known to depend upon:

> "... meteorological factors such as wind velocity, temperature, relative humidity, visibility, lapse of time since the last precipitation and presence or absence of inversion layers and cloud cover in the target area; their surface density, uniformity of distribution and moisture content; topography, geometrical form, and degree of builtupness of the target area; and finally numbers and distribution of sources of primary and secondary ignition from blast and thermal effects."[1]

Another important consideration, which itself depends on the factors listed above in a way that is not too well understood, is whether a firestorm does or does not develop.[2] The strong radial winds of a firestorm tend to keep the fire within the perimeter of the area of ignition, while the intensity of the fire is such that near total destruction is likely within that perimeter.[3] To provide protection from firestorms for individuals in the fire area, shelters need to be sufficiently deep to be insulated from the high temperatures, and equipped either with an air vent that will be clear of

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[1] Ibid., pp. 345-346.

[2] A firestorm is defined in Samuel Glasstone (ed.), The Effects of Nuclear Weapons, revised edition, U.S. Atomic Energy Commission, Washington, D.C., April 1962, as "Stationary mass fire, generally in built-up urban areas, generating strong, inrushing winds from all sides; the winds keep the fires from spreading while adding fresh oxygen to increase their intensity." (Glossary, p. 704.)

[3] However, the "perimeter of the area of ignition" is not easy to define, that is, it is not easy to say at what distances from the weapon the many small fires ignited will be sufficiently numerous (per unit area) to coalesce and involve the area in the firestorm. Nor is it easy to say how effective the firestorm winds will be in preventing the spread (in the direction away from the weapon) of fires that are not a part of the firestorm itself. The answers depend on fuel characteristics and densities, weather conditions, and so on.

burning rubble or with oxygen supply and carbon dioxide disposal arrangements that will permit the shelter to be sealed for a period of perhaps a day or two.[1]

From the point of view of the long term consequences of the war, a firestorm may actually be preferable to a moving mass fire, or conflagration. The latter, characterized by a fire front that moves downwind, may sweep far beyond the area of initial ignition. In fact, the self-limiting character of a firestorm is a major reason for believing that the large factors of firespread assumed in the maximum estimates of area burned are unrealistic. The more likely it is that a firestorm will result from the detonation of a megaton-range weapon, the more likely that minimum areas will be burned. If conditions are otherwise favorable to the development of a firestorm (high fuel density, low humidity, clear day), the main factor determining whether one occurs or not is if the wind velocity is high enough to start the fire area moving downwind before the development of radial winds strong enough to contain the fire.

In areas of relatively low fuel density, such as agricultural areas, small towns, and most suburban areas, a firestorm is unlikely. Scattered small fires or conflagrations may occur, but the fire would not in most cases spread much beyond the area of initial ignition. For example, the Forest Service's maximum estimate for Indiana of firespread from a 10 MT weapon is 1,080 square miles,[2] or about 11 per cent of the nationwide maximum indicated above, and only 13.5 per cent greater than the nationwide minimum. But fire certainly could spread over large areas of forest and grasslands if moving

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[1]A recent article by A. Broido ("Surviving Fire Effects of Nuclear Detonations," Bulletin of the Atomic Scientists, March 1963, pp. 20-23) suggests that the shelter required for survival in a firestorm is not as elaborate as had been generally supposed.

[2]Jewell and Willoughby, op. cit., Table 3.

conflagrations once got established, especially in the drier areas and months. The total area burned may depend very critically on (a) the number of weapons detonated in forest and grassland areas, and (b) the extent to which fires in urban and suburban areas may spread to surrounding forests and grasslands. With respect to (a), large reductions in the area burned could be achieved by a relatively cheap program of preparations for fire control in target areas located in forest or grassland regions where firespread seems likely. (There is a possibility of deliberate targeting of forests and grasslands in an attempt to start forest fires, but this possibility seems remote in view of the urgency of alternative uses of the weapons and the uncertainties in the process of firespread.) With respect to (b), much will depend on the geographical details of the target area involved; but, once again, it seems likely that moderate preparations would be highly effective.

The main fire threat to postattack agriculture almost certainly comes from the long term effects of the burning of forests and grasslands, rather than from the burning of the agricultural areas themselves. The probable extent of firespread in agricultural lands is simply not sufficiently great to make this a problem of the first order of importance. There is no known quantitative assessment of the probable significance for agriculture of the floods, erosion, and ecological disturbances that might result from the burning of large areas of forest and grasslands. However, it seems reasonable to suppose that much of the vast expanse of agricultural land in the Middle West would not be seriously affected, and that the most serious effects would take some years to develop, allowing time for countermeasures to be instituted. Furthermore, if the total area burned over is a relatively moderate percentage of the nation's land area, the effects on the remainder of the country should be minor. But, in applying this standard, there is considerable uncertainty as to what the area burned over is likely to be. Assuming there is no deliberate attempt to start fires in forests and grasslands, the area burned is quite unlikely to exceed that indicated by the Forest

Service minimum estimates by more than a factor of two, and it could well be much smaller.[1] But if twice the minimum area is taken as the basis of the estimate, an attack of not much over 7,500 megatons would burn 50 per cent of the land area of the country.[2] The potential effects of fire on the prospects for economic viability therefore become quite formidable at levels of attack well below the level at which the problem of Strontium 90 contamination of farmland would become severe.

The last, and least understood, of category effects of the war on the natural environment comprises the effects of fire and radiation on the balance of nature. That such effects are possible has been recognized for some time, but so far as I am aware, no study exists today that attempts to provide quantitative estimates of the possible seriousness of these effects or to determine the level of attack, if any, at which the resulting problems might become critical.[3] As a result, the best that can be done here is to list some of the effects that have been speculated about and to point out that at present there is no way of knowing whether the problem is, or is not, of first order importance.

A very simple observation serves to establish the significance of one set of ecological effects. Fallout shelters can protect a large proportion of the human population from the lethal effects of the high radiation levels of the first days or weeks, but they obviously will not accomplish this for the rest of the world of living things. Therefore, depending on the geographical distribution, habits, and sensitivity to radiation of various species, the various forms

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[1] This judgment is essentially that of Hill in the hearings in Civil Defense, 1961, p. 358.

[2] Assuming essentially the same proportions of weapons of various yields as in the 1446 megaton attack for which the estimates are given above.

[3] However, there is a preliminary survey of the problem by H. H. Mitchell, Ecological Problems and Postwar Recuperation: A Preliminary Survey From the Civil Defense Viewpoint, The RAND Corporation, RM-2801-PR, August 1961.

of life may survive the period of high radiation levels in drastically different proportions. And once the ecological balance is seriously disturbed, it is conceivable that the "ecosystem" of the continent may exhibit a dynamics of its own that will carry it even farther from the (proximate) prewar equilibrium. Some species, no longer controlled by their natural enemies, may multiply enormously; others, deprived of their normal sources of food or otherwise affected by the total change in the system, may disappear. Assuming that a rough equilibrium would eventually be reestablished, there is no obvious reason to believe that it would closely resemble the prewar equilibrium.

The available information on the comparative radiosensitivity of different forms of life suggests that major differences in survival rates are quite likely. Mammals are particularly vulnerable to radiation; for most species the lethal dose[1] is within a factor of two (either way) of that for man. Birds are also thought to be within this general range of susceptibility. Some insects, on the other hand, may survive doses several orders of magnitude higher than the dose that would kill a man.[2] Plants in general are much less sensitive than the mammals and birds, but pine trees are about as vulnerable to radiation as man. These facts suggest strongly that an attack that would produce fallout lethal to a large fraction of the unprotected human population would also be lethal to a roughly comparable fraction of the population of most species of other mammals and of birds, and produce severe damage to coniferous forests, but the direct effects on most insect species would be much smaller.[3]

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[1]More precisely, the LD 50, that is, the dose that would result in the death of 50 per cent of the individuals in a group exposed to that dose.

[2]Mitchell, Tables 4 and 5, p. 22.

[3]This was regarded as a likely result by R. F. Reitermeier in the 1959 hearings (Biological and Environmental Effects of Nuclear War, p. 791); however, it was not stressed in the testimony of J. N. Wolfe on ecological effects (pp. 832-842), which, as noted above, was quite pessimistic with respect to other effects.

It is estimated that an attack of about 2000 megatons, surface burst and distributed uniformly over the country, would produce fallout lethal to a quarter of the unprotected human population; 4000 megatons would kill half, and 7000 megatons would kill three quarters.[1] Thus, the potential for major disruption of the ecological balance exists at quite plausible levels of attack. From the point of view of effects on postattack agriculture, it is worth noting that the assumption of uniform distribution over the country may be overoptimistic. Most of the programmed ICBM force is to be located in South Dakota, Nebraska, Kansas, Oklahoma, Arkansas, Montana, Wyoming, Colorado, Arizona, New Mexico, and Texas -- that is, in or upwind of most of the country's important grain and livestock producing areas.[2] On the other hand, for an attack involving large scale city strikes, the concentration of cities on the East Coast would work in the opposite direction. The prevailing winds would carry much of the fallout out to sea.

Although the facts of differential radiosensitivity indicate that nuclear war might well produce major ecological disturbances, they do not carry us very far toward a detailed understanding of the nature of those disturbances or their probable consequences in the short or long run. The details of the habits and habitats of different species, and the geographical distribution and time of year

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[1] H. Everett and G. E. Pugh, "The Distribution and Effects of Fallout in Large Nuclear-Weapon Campaigns," Operations Research, March-April 1959, Fig. 10. These calculations assume the weapon yields are two-thirds fission. The assumption of uniform distribution of the attack over the country means that the conclusions are independent of the geographical distribution of the population, or, to put it another way, that the conclusions apply to the population of any species with the same sensitivity to radiation as man. Also, it should be emphasized that these calculations do not indicate the additional fatalities that would be produced by fallout, but the fatalities that would be produced by fallout if other weapons effects did not exist.

[2] N. A. Hanunian, The Relations of U.S. Fallout Casualties to U.S. and Enemy Options, The RAND Corporation, RM-2747, May 1961, p. 12, for a schematic map of the location of U.S. ICBM sites, and p. 10.

of the attack are likely to be major influences on the proportions in which different species survive the period of high radiation.[1] For example, it has been suggested that insects that spend much of their time on the ground may be vulnerable to beta radiation, which is not likely to be of much importance to larger animals because of its low penetrating ability. This might partially compensate for differential sensitivity to gamma radiation, but this compensating influence would not exist for insects in trees or beneath the surface of the ground. The time of year at which the attack occurs will determine which of the migratory birds will be in the area. Beyond the question of immediate survival, given species will be affected by the fate that has befallen predators, prey, or parasites. For example, birds, bats, frogs, and so on are by no means the only natural controls on insects; other insects, bacteria, and so on, play a role that is probably greater than that of larger animals,[2] and other considerations, such as availability of food, are also highly relevant. Another possibility is a general intensification of disease as a result of the greater radiation resistance of microorganisms and the resistance-reducing effects of radiation in larger organisms.

In relating the ecological consequences of fire and radiation to the economic viability problem, a fundamental distinction must be drawn between the complex natural ecosystems of forests, grasslands, and lakes and the simpler, artificially maintained ecosystems of commercial agriculture. It is quite possible that the various effects of nuclear war might produce enormous, long-lasting disturbances in the natural ecosystems, particularly forests, although not producing any effects on agriculture that would imperil the achievement of viability. Ecological disequilibrium is not an unprecedented threat to commercial agriculture; in fact, it can be regarded as the essence of the system, in the sense that the farmer is constantly

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[1]Also, the radiosensitivity of a given species may differ at different phases of its life cycle, and the sterilizing dose may be substantially below the lethal dose. Mitchell, pp. 22-23 and p. 26.

[2]This has sometimes become apparent when the use of insecticides has produced perverse results. An attempt to control pest A with insecticides sometimes results in the disappearance of insect B which is the natural control for pest C. Pest C then flourishes.

struggling against the competition of weeds, insects, rodents, disease organisms, and so on, that would "naturally" move in and deprive him of a large portion of his produce. From time to time he must face some new challenger in the form of a pest or disease that has been introduced from abroad.[1] Even without the complications introduced by a nuclear war, this battle would soon be lost if pesticides, counter pests, vaccines, disease resistant strains, and the like, were not available; in fact, it would probably be lost if the arsenal of methods of control merely remained constant.

The relevant questions, in the postattack context, are (a) whether nuclear war would so intensify the existing ecological hazards of agricultural production, or produce such qualitatively different hazards, as to make control infeasible with present methods (including research methods), and (b) if control would be feasible with present methods, whether the resources needed for that purpose would be available. A reasonably confident answer to the first question will obviously be difficult enough to obtain, but not nearly as formidable as discovering the ecological effects of the war. The second question relates directly to the survival of particular resources -- certain parts of the chemical industry, certain groups in the labor force, and so on. But, indirectly, it involves the whole complex problem of the capabilities of the reorganizing economy. Here, as elsewhere, the timing of events may be a crucial determinant of the success or failure of viability. The secondary effects of the war on the natural environment -- population explosions in species for which natural controls are removed, erosion by wind and water in the areas where ground cover has been destroyed by fire, radiation or insects, extension of the disequilibrium to areas not directly affected -- will not occur overnight; in some cases they may take years to develop. There will thus be some time for a recovery in the economy's

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[1]It is arguable, in fact, that the world as a whole is at present in a state of severe ecological disequilibrium because the activities of man have resulted in the appearance of ecological competition between species that were formerly isolated from each other by the oceans and other natural barriers. See Charles S. Elton, <u>The Ecology of Invasions</u>, John Wiley and Sons, New York, 1958, for a fascinating examination of this situation and its implications.

capabilities for dealing with these problems.[1] The chances that the time will be adequate can obviously be enhanced by a suitable program of preparedness measures designed to assure a prompt counterattack against developing ecological problems. No such program, however, can justify high confidence in the ability of the economy to handle these problems after attacks of many thousands of megatons, for it is not known with high confidence that the resulting problems would be manageable by any known techniques.

Barring a dramatic improvement in our understanding of the possible ecological effects of massive nuclear attacks, there will always remain a considerable uncertainty about the prospects for resuming agricultural production, and a resulting uncertainty about the prospects for viability. Of course, to say that the outcome is uncertain is not to predict that it will be unsatisfactory. But to the extent that the uncertainty is large, the probability of an outright failure to achieve viability is also large. The existence of such a probability of failure is highly relevant to the case for undertaking expensive programs to deal with the other economic difficulties produced by very large attacks.

This discussion of the resumption of agricultural production is concluded with a brief summary of some of the findings of the Williamson-Moll study with respect to the less esoteric effects of the war on agriculture.[2] First, the degree of fallout protection available for farm manpower would be an important determinant of postattack agricultural output, especially if petroleum is in short

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[1]In particular, it seems likely that the impact of ecological disturbances in forests and other natural habitats would be felt in the agricultural areas only with a considerable lag. In the long run, it may not be justifiable to regard the problems of commercial agriculture as separable from the problem of ecological disturbances in nonagricultural areas. The economy should be more able to cope with the problems in the long run than it will in the first year or two after the war.

[2]O. Williamson and K.D. Moll, Postattack Farm Problems, Part II: Attack Effects on Inputs and Farm Output, Stanford Research Institute, October 1961.

supply and manpower must be substituted for it to some extent. If the farm population had shelter about equivalent to that provided by an ordinary basement (protection factor of 20) and if surviving members of the labor force who lived on farms but were not employed there preattack were added to the postattack farm labor force, the labor input per uncontaminated acre could be 50 to 100 per cent above preattack levels.[1] If members of this potential farm labor force took no steps to protect themselves from fallout, the resulting reduction in postattack agricultural output might be about 13-1/2 per cent for an attack of 1500 megatons, and would be considerably greater for larger attacks.[2]

Both petroleum and pesticides production are highly vulnerable to attack on industrial targets. The high degree of geographical concentration of petroleum refining was noted at the beginning of this section. It is estimated that reduction of fuel use in agriculture to one-half of normal would, with no change in labor input, reduce agricultural output by about one-fourth. Fuel supplies on farms and in bulk storage in rural areas might meet a significant fraction of requirements in the first year in which production is resumed.[3] Pesticides production is, in general, a complicated matter involving several stages of chemical processing, and different stages may be carried on at different locations, and is particularly likely to be affected by the general disruption of transportation and the market mechanism, as well as by direct damage. In important cases, production of particular pesticides is entirely dependent on the survival of only one or two plants. The total loss of all pesticides might be expected to reduce agricultural output by about 15 per cent in the first year, even if the ecological effects of the war did not

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[1] Ibid., p. 188.

[2] Ibid., p. 191.

[3] Ibid., p. 56.

significantly increase the pest problem. Effects would be greater in subsequent years if the shortage continued.[1]

Postattack production of meats and dairy products is likely to be well below preattack levels unless measures are taken to protect farm animals from fallout and to provide them with food and water during the first days or weeks. Beef cattle on the open range would be in the most vulnerable situation; cattle in feed lots, hogs, and milk cows could be provided with a moderate degree of protection simply by keeping them in an ordinary wooden shed for the first few days. In spite of the low shielding factor, this degree of protection could be quite effective, over the country as a whole, in increasing the percentage of animals surviving. Assuming that unsheltered animals are lost in areas where the H+1 intensity exceeds 100 r/hr, and sheltered animals are lost if the intensity exceeds 1000 r/hr, the SRI study concludes that two-thirds of the livestock would survive the 1500 MT attack.[2]

PROBLEMS OF THE NETWORK INDUSTRIES

The geographical distribution of economic activity has been largely ignored in the preceding discussions of the balance between population and resources and the problems of meeting subsistence consumption requirements. The balances that have been struck have been national balances, relating to the economy as a whole. But, a satisfactory relationship might be indicated in the nation as a whole when, in fact, the surviving resources were so distributed among isolated regions and localities as to leave the economy with very little productive capability at all. As was suggested previously, the problem of remedying such a situation might be formidable because of the strong self dependence relations involved.

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[1] Ibid., pp. 153-171, and K. D. Moll, Jack H. Cline, and Paul D. Marr, Postattack Farm Problems, Part I: The Influence of Major Inputs on Farm Production, Stanford Research Institute, Menlo Park, California, December 1960, p. 124.

[2] Moll and Williamson, pp. 31, 32, 36.

It is the function of transportation (in the broadest sense[1]) to make the geographical distribution of other economic activities irrelevant. In a world where transportation service was perfect -- free and instantaneous -- the geographical distribution of activities other than transportation and the extractive industries would be indeterminate and of no economic consequence. Mesabi ores could be supplied to the steel plants of Birmingham, Alabama, or Geneva, Utah as easily and cheaply as to those of Chicago and Pittsburgh. Packing plants in California could slaughter cattle raised in Iowa and serve markets in New York. However, if this perfect transportation system had the network character of existing transportation systems, the geographical distribution of the transportation system itself would obviously not be a matter of indifference -- it would have to relate to the distribution of all other activities whatever that might be. If an economy equipped with such a transportation system were to suffer severe damage in a war, the geographical distribution of activities other than transportation and extractive industries might again have some economic relevance, because the transportation capabilities that made it irrelevant would be partially destroyed. This would not be a necessary result since it could happen that the geographical distribution of damage to the transportation network and to other types of capacity would be such as to leave all surviving nontransportation capacity adequately supplied with transportation services.

For purposes of assessing the viability implications of alternative geographical patterns of destruction, it is a reasonable approximation to regard the American transportation system as perfect. This statement amounts to an assertion that the geographical distribution of surviving capacity is likely to be of second order importance

[1]That is, transportation not only of persons and commodities, but also of electric power (electric power distribution), water (water supply systems), sewage (sanitary systems), and information (communications).

except insofar as it relates to the ability of the surviving transportation system to "connect" all the surviving resources. Some increases in transportation costs would undoubtedly be imposed because the average distance between geographically separated stages of production processes would be increased. These costs are likely to pose a negligible obstacle to the achievement of viability in relation to the consequences of damage to the transportation system.[1]

Unfortunately, there is no way of providing a significant amount of insight into the character and magnitude of postattack transportation problems by simply citing a few statistics. General conclusions cannot be drawn except, possibly, as a summary of detailed investigations relating to a wide range of alternative situations. The details that must be considered include not only the details of the operation of the transportation system as a system, but also the details of the geographical distribution of surviving capacity in all other industries and the details of the program that is to be followed in achieving viability -- a program that should depend in turn on the capabilities of the transportation system. For example, it is not possible to set forth an aggregative measure (such as ton-miles) of the transportation capabilities of the railroads that does not depend heavily on the assumptions made as to geographical patterns of freight movements and the commodities to be carried. In short, it is virtually impossible to separate the problem of postattack transportation from the total viability problem. The required studies of transportation within this total context have yet to be made, and there is not any prospect that they will be made in the foreseeable future.

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[1]See Section IV for a discussion of some examples of higher transportation costs that might be imposed by the geographical distribution of surviving resources even if the transportation system itself were left intact. The assertion that these costs would be of second order importance would be justified not only by comparing these cost increases to other obstacles to reorganization, but also by considering the probably geographical patterns of destruction and the adjustments that could be made to avoid large increases in transportation requirements.

A few statistics will now be cited that obviously provide only an insignificant amount of insight. The discussion is confined to transportation in the usual sense, and in particular to railroad and truck transportation. First, the capability of the existing transportation systems substantially exceeds what might reasonably be regarded as postattack requirements. The study by Bear and Clark estimated that the postattack demand for transportation (measured in dollars of service at 1947 prices) would be 49 per cent of the 1956 output of transportation services;[1] and the 1956 output was undoubtedly well below system capacity, especially in the case of the railroads. It should, therefore, be possible to meet essential transportation requirements after very substantial damage had been inflicted on the system, providing the surviving components of the system could be made to function as a system, and providing that the portions of the system destroyed mainly served destroyed rather than surviving areas. These provisions are precisely the reason why an aggregative comparison of supply and requirements does not suffice, but it is worth noting that it is not inevitable that such a comparison should prove to be reassuring.

Second, the transportation system of the United States is very well endowed with railways and highways, and, in comparison with other economic resources, these are quite "hard" and well dispersed. Furthermore, in the eastern half of the country[2] the networks are so dense that satisfactory detours around areas of blast damage or high radiation intensity would generally be available. Table 9 shows,

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[1] See The Importance of Individual Industries for Defense Planning -- Supplemental Data, op. cit., Table IIIc, p. 32. This estimate assumes 60 per cent population survival, and represents the transportation requirement for a postattack GNP equal to half the 1956 GNP.

[2] For this purpose, the eastern half of the country is defined as extending to the first tier of states west of the Mississippi.

TABLE 9

EQUIVALENT SQUARE GRID SIZE FOR RAILROAD AND HIGHWAY NETWORKS OF THE UNITED STATES AND MAJOR SUBREGIONS, 1960

(miles)

Region	Railroad network[a]	Highway network[b]
Continental United States	27.9	1.4
New England	21.9	2.1
Middle Atlantic	11.8	1.3
E. North Central	12.7	1.2
W. North Central	22.3	2.1
South Atlantic	20.4	2.2
E. South Central	23.9	1.7
W. South Central	31.0	3.5
Mountain	80.9	11.2
Pacific (excluding Alaska and Hawaii)	41.0	4.3
Alaska	2050.3[c]	303.4
Hawaii	513.9[c]	5.7

Notes:

[a]Twice the area (including water area) of the region divided by the mileage of "first track" road in the region (that is, excluding sidings, yard track, and main line tracks).

[b]Twice the area of the region (including water area) divided by the mileage of surfaced rural road in the region. "Rural" road is road outside of incorporated places, New England communities of 2500 or more inhabitants, and some of the more populous unincorporated places.

[c]Indicated grid size exceeds total mileage of line.

Source:

Statistical Abstract of the United States, 1962, U.S. Department of Commerce, Washington, D.C., 1962, pp. 170, 552, 574.

for the conterminous United States and for major regions, twice the ratio of the area to (1) mainline railroad mileage, and (2) surfaced rural road mileage. This ratio has the following geometric interpretation: if the region involved were square and were covered with a network in the form of a square grid such that the total length of the lines in the grid equaled the length of the actual (railroad or highway) network, this ratio would represent the size of a square in the grid. Thus the ratio represents, in a certain sense, the average distance between network links going in the same direction.

The situation in the Mountain States and the Pacific Coast states is quite different. Rail access to large areas could be denied by quite a small number of weapons. In fact, it appears that by exploiting the points at which major roads cross each other, less than ten weapons would suffice to destroy all rail connections between the Pacific Coast states and the rest of the country. Connections along the Pacific Coast could also be wiped out very easily. Furthermore, the average density of the network does not provide, in these regions or elsewhere, a reliable indication of the seriousness of the problems that would be created if the attacker set out to break up the network. Where the network crosses major natural barriers (major rivers, mountain ranges) the length of the detour that would be necessitated by the destruction of a single bridge or tunnel[1] is probably a good deal longer than the average detour that a random cut in the network would require. And, of course, the construction effort required to restore the damaged links would be greater if bridges and tunnels were destroyed than if an equal length of ordinary track or highway were affected.

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[1]It may well be that a rail line or highway passing through a narrow mountain canyon is as vulnerable, or more vulnerable, than one that passes through a tunnel. A well placed megaton weapon might eliminate the usefulness of a canyon as a passage through the mountains. If so, links passing through such canyons should be added to the list of points at which the network is particularly vulnerable and reconstruction would be costly and time consuming.

However, a deliberate attack on network links is quite improbable, for the simple reason that the transportation system is much more vulnerable to other types of attack.

An attack on a large number of major cities would not only break many links of the railroad and highway network, but, more importantly, it would destroy large amounts of rolling stock, kill experienced personnel (particularly managerial personnel), and destroy railroad classification yards, communications systems, and other essential components of the railroad and highway transportation system. Losses of these inputs are likely to have much more serious effects on the functioning of the system than the occasional situations where access to a region is difficult or impossible because of the destruction of network links.[1] Even assessing the damage to these components that would result from a given attack, let alone relating these losses to system capability, is a complex matter and is hampered by inadequacies in the basic statistical data. However, some suggestive estimates were presented in a Stanford Research Institute study of railroad transportation.[2]

Damage to components of the railroad transportation system was assessed for a 1500 megaton attack on military and population targets (among others). It was estimated that the blast effects of the attack would destroy 46 per cent of the major railroad classification yards, 36 per cent of the freight cars, 29 per cent of the line-haul locomotives, 48 per cent of the switching locomotives, 30 per cent of the repair shops, 32 per cent of railroad diesel fuel stocks, and would

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[1] Of course, the capacity of network links into a particular region may be greatly reduced without making access completely impossible. Since there is a considerable amount of substitutability between network links on the one hand and all other system components on the other, it is not strictly meaningful to discuss losses except in terms of losses of capability in the system as a whole.

[2] H. L. Dixon, D. G. Haney, and P. S. Jones, A System Analysis of the Effects of Nuclear Attack on Railroad Transportation in the Continental United States, Stanford Research Institute, Menlo Park, California, April 1960.

kill 29 per cent of the experienced labor force.[1] An additional 38 per cent of the experienced labor force would be killed or disabled if they took no action to avoid exposure to fallout, and fallout would also make varying amounts of the other components unavailable for varying periods of time.[2] Only two of the seventy-eight major links in the SRI model of the railroad network would be entirely broken by the attack -- San Francisco to Los Angeles, and Baltimore to Tampa.[3] Losses of components and experienced personnel would have a serious impact on the efficiency with which the surviving rolling stock and network would be used. The SRI study concluded, however, that the capabilities of the system would be adequate to support distribution of food stocks to the surviving population (assuming good fallout shelters are available) after the 1500 megaton attack; in fact, if deficiencies in classification capability at a few of the nodes of the network could be overcome, the system could handle the pattern of freight movement that would result if the freight requirements of food distribution were increased by a factor of three.[4]

Somewhat heavier attacks might make it impossible to meet the food distribution requirements if substantial additional losses of classification capability occurred. Determination of whether this is in fact the case would require examination of a broader range of measures for improving the capabilities of the postattack system (including, for example, some amount of repair and reconstruction) than is considered in the SRI study.

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[1] _Ibid._, Table 1, p. 9.

[2] _Ibid._, Table 14, p. 62.

[3] _Ibid._, Figure 15, p. 111.

[4] Since the capabilities of the system cannot be measured except in relation to a particular pattern of freight movement, the margin by which capabilities exceed requirements must be expressed in terms of the size of the proportionate expansion in requirements that would still leave the system capable of meeting them.

Although the fuel input to railroad and truck transportation would probably account for a very small fraction of essential postattack requirements for petroleum products, the petroleum refineries may nevertheless be the critical vulnerability of the transportation system in the sense that an attacker who could allocate 150 weapons to the task of disrupting the nation's transportation system might well be unable to find a more effective way to use them. The short run effects of such an attack would of course be much smaller than the effects of an attack of equal magnitude on classification yards and a few critical network links, for example. As long as fuel stocks lasted, the trains and trucks would move. But in the longer run the combination of dwindling stocks and urgent demands for petroleum products from other sectors might create a more severe constraint than destruction of classification yards and network links (with incidental destruction of rolling stock, and so on). Once again, detailed analysis of possible system adaptations to various postattack conditions would be required to determine whether this speculation is correct or not.

To sum up, a major improvement in understanding the role of the transportation system (now taken in the broad sense again) in achieving viability would require much more detailed analyses of the postattack economic situation than have been carried out thus far, and it is unlikely that such analyses will be made in the near future. But it would not be impossible to justify reasonable confidence in the ability of the transportation system to meet essential requirements after plausible attacks if appropriate preparedness programs were undertaken. Such programs may greatly reduce uncertainties that cannot be reduced by any amount of analysis, as has been emphasized repeatedly. At a price, the nation could have dispersed stockpiles of materials necessary for the repair and reconstruction of railroad lines, highways, power lines, telephone lines, water supply systems, and so on; it could have plans for economizing on the use of classification yards, or it could stockpile the most critical materials and components; it could have, in each city, trained (and sheltered!)

cadres prepared to accomplish the repair of the various networks; most important, it could assure the existence of a postattack organization capable of identifying the most serious problems and making a reasonable allocation of available resources among the various reconstruction efforts. It is difficult to say what the price would be. But determining the content, cost, and probable effectiveness of a program of this type would be much easier than determining the probable postattack outcome under the present state of preparedness. The price might reasonably be expected to be well into the billions of dollars; it seems very unlikely that it would run to multiple tens of billions. Whatever the price, along with realistic organization preparations, it is the only way of reasonably calculating the economic consequences of nuclear wars involving large scale attacks on cities or other economic targets.

CONCLUSIONS

The preceding pages provide no more than a sketch of the many factors that must be taken into account in attempting to delimit the range of postattack situations under which the achievement of economic viability would be technologically feasible. However, a general remark that the problem is complicated and deserves further study is hardly a satisfactory conclusion to an inquiry the basic premise of which is that a quantitative assessment of the probable economic consequences of a thermonuclear war is an essential part of the process of formulating sound national security policy. Although the facts set forth above and the more detailed information that is available do not yield a definitive answer to the questions addressed, they certainly impose some limits on the answers that could plausibly be given. Therefore, I will set forth some informed speculations on these questions, but the reader is warned against taking these quantitative statements too literally.[1]

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[1] The quantitative statements made are based on the survival curves given at the beginning of this section, on the estimates of deaths and casualties presented by N. A. Hanunian and by H. Everett and G. E. Pugh, on miscellaneous sources, and on a good deal of judgment.

It is hardly possible even to describe the full range of conceivable postattack situations, let alone to express a judgment about each of them. The situations examined are those consistent with the following general assumptions: (1) The United States does not suffer a decisive defeat in the war, that is, at a minimum it is left free to conduct its domestic affairs as it wishes; (2) Latin America, Australia, and Africa are not significantly damaged in the war and are willing to trade with the United States on terms not spectacularly inferior to prewar world price ratios, but gratuitous assistance to the United States in its reorganization effort is negligible;[1] (3) The fixed requirement is negligible;[2] (4) The level of subsistence consumption in the first two or three years is not much above physiological subsistence; (5) No significant decline in the effectiveness of surviving members of the labor force occurs as a result of radiation explosures less than those that produce symptoms of mild radiation sickness, or as a result of psychological reactions to the war and the postwar situation; (6) Most of the weapons employed against nonmilitary targets have yields well up in the megaton range, so that the number of weapons involved is not more than, say, one-fifth of the total yield in megatons. Finally, it must be emphasized that

[1]"Negligible" means, in this instance, less than $5 billion a year from all sources. Aid of this magnitude might be very important in terms of results, if it served to alleviate critical bottlenecks. However, in such situations the United States could probably manage to find something to export in order to accomplish the same results. Presumably, the United States could not and would not want to rely on any other nation to serve the kind of organizing function that the United States played in Germany after World War II. Canada might be an exception to this, if it happened to come through the war in much better shape than the United States.

[2]National security expenditures (including foreign aid) plus support of nonproductive survivors would not take a larger share of postattack output than national security expenditures currently take of GNP. Other government expenditures should be regarded as consumption or investment for purposes of viability analysis.

technological feasibility is being discussed, and not the actual outcome under any given set of measures for dealing with the organizational aspects of the problem.

Given these general assumptions, the various situations that might arise will be distinguished according to two characteristics: (1) the total weight of attack on the United States; (2) the weight of attack directed against nonmilitary targets.[1]

Total Weight 1000 Megatons or Less, 500 Megatons or Less on Nonmilitary Targets

Under these conditions, I feel that a failure to achieve viability would be very unlikely, regardless of the targeting of the nonmilitary portion of the attack, and regardless of the measures taken to protect the population. At worst, 100 weapons would be directed against nonmilitary targets. Casualties might approach half of the population in the worst case, but could be much smaller if: the population were moderately prepared, less than 500 megatons were directed against nonmilitary targets, and/or most of the weapons were air burst.[2] The surviving population should not have much difficulty in supporting itself. If the nonmilitary part of the attack were directed at population, per capita availability of most economic resources would not be far below prewar levels. Severe bottlenecks might be created in some narrowly defined industrial categories if the attacker attempted this, but the general adequacy of surviving resources, the food stockpile, and the possibility of trade should certainly make it possible to alleviate these bottlenecks in time.

[1]For the purposes of this discussion, "military targets" means the U.S. strategic retaliatory force, and "nonmilitary targets" means everything else, except that a small number of important strategic retaliatory force targets are located in or near large cities, and attacks on these would count as part of the nonmilitary attack. On this definition, the destruction of physical capital incidental to a pure military attack would be negligible, though population casualties and other effects might be substantial.

[2]"Casualties" and "deaths" are not equivalent terms; the former includes injuries.

For example, an attempt to create a bottleneck in petroleum refining would not come very close to reducing capacity to zero and would leave the rest of the economy in fairly good condition. If the proportion of the country's area covered by all weapons effects (including fallout) is any guide, the changes produced in the natural environment should not be serious.

Total Weight 1000 to 4000 Megatons, 500 Megatons or Less on Nonmilitary Targets

If all or nearly all targets were attacked with air burst weapons, the prospects for viability after attacks in this range would be about as good as in the previous case. The effects on the nation's industrial plant would be essentially the same, and would be unlikely to pose critical problems. For plausible geographical distributions of the attack, a significant fraction of the country's area might be burned over, but the prospects for postattack agricultural production should not be seriously affected in the short run. If the attacker used surface bursts against most targets, the effects of fallout might create serious obstacles to viability. First, an attacker who used 500 megatons against nonmilitary targets and sought to maximize "bonus" damage from a 3500 megaton attack on military targets could kill a large fraction of the population -- 60 per cent or more -- if no fallout shelters were available. Total casualties might approach 80 per cent of the population. Such a low level of population survival would by itself make the achievement of viability very difficult.[1] Second, a substantial intensification of the pest problem in agriculture would be a possible consequence of the ecological imbalances produced by the period of high radiation levels. The economy would be much less capable of dealing with this problem than it was preattack (even if the attacker did not devote special attention to the pesticides industry), unless special preparations were made. No firm prediction about

[1]Important skill groups in the labor force would be totally wiped out, and the resulting problems at the strictly organizational level would be enormous.

the seriousness of the resulting situation is justified, but the possibility of a major pest problem introduces some uncertainty into the picture.

Certain preparations would have to be made in order to give the economy a "medium confidence" capability for viability after the worst of the attacks in this range. First, the population would have to be moderately well protected against fallout -- the equivalent of protection in an ordinary basement, with windows sandbagged, and stocked for a two week stay. This would probably reduce casualties below the 50 per cent level. Second, preparations would have to be made to assure that production of pesticides could quickly surpass preattack levels, and to guarantee a capability for investigating, analyzing, and attacking pest problems as they appeared. Third, preparations would have to be made for quick restoration of the network industries, and the alleviation of specific bottlenecks elsewhere. The cost of preparedness program of this sort might be expected to be in the one to ten billion dollar range.

Total Weight 1000 to 4000 Megatons, 750 to 2000 Megatons on Nonmilitary Targets

It is believed that this is the range where the loss of industrial capacity would create serious to insuperable obstacles to viability, unless extensive preattack preparations were made. Much would depend on whether the attacker did or did not attempt to maximize the economic difficulties created by the nonmilitary portion of the attack; but if not, the change from the preceding case would be that an additional 15 to 20 per cent of the population would be killed, the balance between surviving population and resources would be less favorable, and there would be more industrial categories in which capacity was reduced close to zero. Good to excellent[1] fallout

[1] By "excellent" fallout shelter is meant something of the sort investigated by the U.S. Naval Radiological Defense Laboratory, with a radiation attenuation factor of 100, resistant to 35 psi of blast overpressure, and affording protection against firestorm as well. (See the testimony of W. E. Strope, Civil Defense, 1961, pp. 233-257.)

shelter would be required to keep casualties below 60 per cent of the population. The over-all balance between industrial capacity and population would not be at an obviously disastrous level, even if population survival were well above 50 per cent. It might be possible to achieve viability if the effects on the natural environment did not create a highly unstable ecological situation and preparations were made for dealing with these problems, and if the numerous specific bottlenecks could be alleviated. The last might be accomplished through foreign trade, except that it would be difficult to produce anything for export; and, in addition, a very large fraction of the country's port capacity would certainly be destroyed. Success in achieving viability, without the benefit of more extensive preparations than have thus far been considered, seems quite unlikely.

If the attacker did choose to attempt to maximize economic difficulties, success would be even less probable. How severely the economy could be crippled by an attack of 2000 megatons in at most 400 weapons is not considered in detail. However, it seems probable that such an attack could destroy 100 per cent of the port capacity and petroleum refineries, incidentally destroying perhaps 40 to 50 per cent of other industrial capacity in general, with some weapons left over. Those additional weapons might well reduce survival in additional industrial categories to close to zero. For the attack pattern that would produce these results, about two-thirds of the population might survive, if excellent fallout shelter were available. Although the food stockpile would last for two or three years, it seems very doubtful that this period would suffice for piecing together the economy after such an attack.

The over-all balance between resources and population would not be critical, and therefore the preparations required to make viability possible after attacks in this range (in addition to those already mentioned) would involve a relatively selective program of stockpiling, construction of underground factories, and so on, in order to forestall the appearance of certain bottlenecks, plus more elaborate preparations to restore transportation, communications, and other

services not readily stockpiled or moved underground, plus general preparations to facilitate the repair or partial salvaging of damaged capacity. It is probable that an adequate program of this sort might cost in the low tens of billions of dollars. Of course, if effects on the natural environment turned out to have particularly serious consequences, viability might be unattainable in spite of this degree of preparation.

Total Weight Over 6000 Megatons, 2000 Megatons or Less on Nonmilitary Targets

This case differs from the preceding in that it is no longer necessary to appeal to the possibility of unstable behavior of the ecological system in order to conclude that over most of the area of the country, major uncertainties exist about the prospects for post-attack agriculture. The results would, of course, depend quite heavily on the attack pattern.[1] But a fairly even distribution of a 5000 megaton attack over the nation might well result in the burning of 20 to 40 per cent of the nation's area and (if most weapons were surface burst) in levels of radiation lethal to unprotected mammals and birds over 50 to 80 per cent of the nation's area. Unless and until a convincing case can be made that feasible preparations would make these problems manageable, the resulting uncertainties about the prospects for postattack agriculture are a major qualification to any calculation of the potential benefits from economic preparations more extensive than those discussed above. Perhaps an economy could be constructed that would be viable as a heavy importer of foodstuffs and exporter of manufactures. If this is a realistic possibility,[2]

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[1] In particular, a pure military attack in which all weapons were air burst and several weapons were assigned, on the average, to each target would be very unlikely to make viability impossible. The relevance of the several weapons per target condition is that the areas burned over would be much smaller.

[2] It is doubtful; but it might be possible if the effects on the natural environment did not extend to Canada.

the program of preparations that would make it feasible would be markedly different from that based on the assumption that the United States would feed itself, and would probably cost a good deal more.

Total Weight Over 6000 Megatons, or 3000 Megatons or More on Non-military Targets

A discussion of still more catastrophic situations is of interest only because further study might lead to a substantial reduction in the uncertainties relative to postattack agriculture, or to the discovery of high confidence ways of meeting the problems. After an attack of 3000 or more megatons (up to 600 weapons) on economic targets, economic viability could be achieved only with the help of preattack preparations that would essentially amount to creating an underground economy sufficiently large and well stocked to be able to meet the subsistence needs of the population after the attack, with little assistance from surviving resources above ground. The construction of such an underground economy would, of course, be a much smaller job than "moving the entire economy underground." In fact, judging by the past accomplishments of the American economy, it is almost certainly a feasible job if carried out over a period of three years or more. My guess would be that $600 billion substantially overstates the cost of the "sub-economy"[1] plus excellent shelters (with a good deal of blast protection) for the population.[2]

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[1]This is O. Morgenstern's term. See his proposal for such an economy in The Question of National Defense, Vintage Books, New York, 1961.

[2]The reasoning underlying this estimate (such as it is) is as follows: An excellent system of fallout shelters should not cost more than $50 billion at the outside; this sum, in fact should buy systems sufficiently "luxurious" to be habitable for a long period of time after the attack. (See the testimony of W. E. Strope, Civil Defense, 1961, pp. 240-245, for discussion of the costs of less "luxurious" shelters.) The stock of privately owned plant and equipment was worth something under $800 billion in 1960 (in 1960 dollars). Considering the low share that subsistence consumption would take of 1960 GNP, the fact that some surviving resources above ground could be counted on, and the fact that the composition of the stock of plant and equipment placed underground could be chosen with postattack needs in mind, it should certainly be possible to get along on one-fourth of

This is $200 billion a year for three years. Suppose (to be realistic about the environment in which such a program might be adopted) that other defense expenditures are running at the rate of $100 billion a year, so that total defense expenditures would be $300 billion a year for the three years. In 1964, operating full blast (World War II conditions), the economy will probably be capable of a GNP of $725 billion or so (1960 dollars).[1] This means defense expenditures equal to about 41 per cent of GNP, just about the same as in 1943 and 1944. Perhaps another year should be allowed for the buildup to this level of expenditure to occur. On the other hand, a large fraction of the expenditure would create capacity that could be put to use before the total program could be completed; that is, the economy would be capable in the later years of a GNP considerably in excess of $725 billion. Thus, subject to the very important qualification that the problems created for agriculture by the changed natural environment must be shown to be manageable, and that three or more years are available

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the 1960 total or about $200 billion worth of plant and equipment (in roughly equal proportions) if the capacity were created above ground. In many manufacturing industries, it appears that underground plants might well be cheaper than plants of equal capacity on the surface, and in only a few industries would costs of subsurface construction be more than twice the costs of ordinary construction. But in some manufacturing industries, and certainly in the case of transportation, major technological advances would be necessary to make underground operation feasible. In these cases, the best solution might well be to stockpile materials, equipment, and components for creating the required facilities on the surface, and to provide the remainder of the underground economy with inventories large enough to support operations until construction could be completed. A factor of three increase over normal plant costs, or a factor of two in plant and equipment combined, should be an adequate allowance for the costs of going underground. This accounts for $400 billion of our estimate. Another $50 billion may be allowed for underground government facilities, water decontamination facilities, hospitals, libraries (especially of technological information), and so forth. This leaves $100 billion for stocks of basic and semifinished materials, including augmentation of the food inventory, and miscellaneous needs.

[1]This assumes that full employment GNP will grow at an annual rate of about 3.5 per cent, starting from 1960, and that "full blast" GNP exceeds full employment (4 per cent unemployment) GNP by about 20 per cent.

for the task, and subject to the six assumptions made above, it may be concluded that it would be economically feasible to make preparations to assure at least the technological possibility of achieving viability after very large nuclear attacks. Although it is not within the scope of this study to discuss the desirability of undertaking such a program, it should be noted that a decision to embark on such a program might provoke a decision on the part of the Soviet Union to develop the means to negate it.

Appendix A

AN AGGREGATIVE MODEL OF THE TECHNOLOGICAL CONDITIONS FOR ACHIEVING VIABILITY

The aggregative analysis presented in Section III is extended and given a more formal treatment in this appendix. The assumptions made and notation employed are the same as before.

The economy is nonviable at time t = o if the surviving capital stock is too small to permit the production of an output large enough to meet subsistence, replacement of depreciated capital, and the fixed requirement. Formally, let $\bar{K}$ be the solution to the following equation in K:

$$L\, p(\frac{K}{L}) = cL + dK + R. \qquad (1)$$

Then the economy is nonviable if $K_0 < \bar{K}$.[1]

If the surviving food inventory is zero, reorganization is impossible. At best, it may be possible to produce an output large enough to cover subsistence and the fixed requirement for a short time, until the failure to replace depreciated capital reduces the capital stock to the point where even this becomes impossible. However, if $S_0 > 0$, then for S_0/cL time periods the subsistence needs of the labor force can be met out of inventory. In the meantime, the excess (if any) of the economy's output over the sum of depreciation and the fixed requirement can be devoted to net investment, so that the capital stock changes according to:

$$K_{t+1} = K_t + L\, p(\frac{K_t}{L}) - dK_t - R. \qquad (2)$$

[1]It could happen that

$$L\, p(\frac{K_0}{L}) < cL + dK_0 + R$$

and

$$K_0 > \bar{K}.$$

This would be a situation in which the surviving capital stock was so large relative to the labor supply that the marginal product of

This relation yields an increase in K only if $L\ p(K_t/L) > dK_t + R$. Hence, if $L\ p(K_0/L) \leq dK_0 + R$, the capital stock cannot be increased at all, and viability cannot be achieved. But if positive net investment is possible, the capital stock can be increased at least as long as the food inventory holds out.[1] The question of whether viability can be achieved is then a question of whether the capital stock K* yielded by difference equation (2) at time S_0/cL is greater than or equal to $\bar{K}$.

In comparing different postattack situations within the framework of this model, it is useful to have a measure of the technological ease or difficulty of reorganization that corresponds to the intuitive idea of the amount of scope for departures from a perfectly implemented policy strictly oriented toward reorganization. Such a measure should have several properties. First, it should obviously be technologically determined, rather than being subject to influence by discretionary changes in policy. Second, it should yield the same value for ease of reorganization in all situations in which reorganization is just

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capital, $p'(K_0/L)$, was less than the depreciation rate, d, and the large depreciation requirement, dK_0, accounted for the "nonviability." However, this situation hardly deserves to be called a case of nonviability, since a failure to replace depreciated capital will reduce the capital stock, thus moving the economy closer to a situation where it could meet all three of the claims on output. This assumes, of course, that there would be no futile effort to preserve the capital stock by sacrificing the labor force.

It should also be noted that there might be no value of K that would constitute a solution to equation (1). This would be the case if no value of K/L satisfied the inequality

$$p(\frac{K}{L}) \geq c + \frac{R}{L} + d\ \frac{K}{L}\ .$$

It is naturally assumed that some value of K/L would satisfy this relation if R = 0, for otherwise the economy could not have been viable preattack. Hence a situation in which the relation could not be satisfied would be one in which reorganization was made impossible by an excessive fixed requirement. In the remainder of the discussion, it is assumed that R is not so large as to preclude a solution to (1). Of course, for many possible functions p, this will be true regardless of the size of R.

[1]It can be shown that, because $p'' \leq 0$ and assuming $p' > d$, the time path of the capital stock yielded by (2) will be monotonic.

on the margin of feasibility. Third, it should be in per capita terms; a measure of ease in absolute terms would be extremely misleading if the comparison were between situations with very different values of L. Fourth, it should compare different postattack situations as of the same point in time; it would be inappropriate to compare economies as of the time viability is achieved if those times differed by a large amount.

A measure satisfying these conditions can be based upon the largest capital stock that it would be technologically feasible to attain in T time periods after the attack, where T is an arbitrary number larger than any of the reorganization periods under consideration. This capital stock K_T will be attained if equation (2) holds until the food inventory is exhausted and equation

$$K_{t+1} = K_t + L\ p(\frac{K_t}{L}) - cL - dK_t - R \qquad (3)$$

holds thereafter. Then $K_T/L - \overline{K}/L$, referred to as "nonessential capital per capita," can be taken as the measure of ease of reorganization. A negative value of this measure indicates that reorganization is technologically infeasible. If reorganization is just on the margin of feasibility the measure will have the value zero, since equation (3) indicates that the capital stock will remain permanently at $\overline{K}$. It should be emphasized again that equations (2) and (3) do not necessarily describe the actual or desirable time path of the capital stock in any case where reorganization is not on the margin of feasibility.

Changes in the values of most of the parameters of the model affect the ease of reorganization in an obvious way. An increase in c, d, or R will make reorganization more difficult, whereas an increase in K_0 or S_0, or an upward shift in $p(K/L)$ will have the opposite effect.

The total effect of an increase in L, however, is not so obvious. An increase in L reduces S_0/cL, the time available for reorganization. However, it also reduces the equilibrium capital stock per capita, as

may be seen by regarding equation (1) as defining an implicit function $\overline{K}/L = f(L)$, and differentiating the implicit function. The result is

$$\frac{d}{dL}\left(\frac{\overline{K}}{L}\right) = \frac{-R}{(p' - d)\,L^2} \tag{4}$$

which is negative if $R > 0$, and zero if $R = 0$. Finally, in addition to affecting the time available for reorganization and reducing $\overline{K}/L$, an increase in L increases the output of the economy at every point of time and thus results in a more rapid increase in K.

In order to determine the net result of these three effects, it is necessary to make more specific assumptions about the function $p(K/L)$. The case in which $p(K/L)$ is a linear function will now be examined in detail. This assumption makes for analytic simplicity, and can, if desired, be regarded as involving the use of a linear approximation to a nonlinear function.[1]

Let $p(K/L) = a + b(K/L)$, and substitute in equation (2). The result is

$$K_{t+1} = K_t + aL + bK_t - dK_t - R \tag{5}$$

or:

$$K_{t+1} = aL - R + (1 + b - d)\,K_t. \tag{5a}$$

It is naturally assumed $b > d$, that is, capital produces some net output. The solution of the difference equation (5a) is

$$K_t = \frac{R - aL}{b - d} + (1 + b - d)^t\left[K_0 - \frac{R - aL}{b - d}\right]. \tag{5b}$$

It is necessary for $K_0 > (R - aL)/(b - d)$, that is, $aL + bK_0 > R + dK_0$, if success in reorganization is not to be ruled out by the impossibility of increasing the capital stock at all.

When the food inventory is exhausted, the capital stock may be as large as K^*, where

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[1]The question of what approximation should be used when judging the feasibility of reorganization is discussed below.

$$K^* = \frac{R - aL}{b - d} + (1 + b - d)^{\frac{S_0}{cL}} [K_0 - \frac{R - aL}{b - d}]. \tag{5c}$$

Reorganization is technologically feasible if $K^* \geq \bar{K}$. The value of $\bar{K}$ is the solution to

$$aL + b\bar{K} = cL + d\bar{K} + R \tag{6}$$

that is,

$$\bar{K} = \frac{R - aL}{b - d} + \frac{cL}{b - d} . \tag{6a}$$

Substituting for $(R - aL)/(b - d)$ from (6a) in (5c),

$$K^* = \bar{K} - \frac{cL}{b - d} + (1 + b - d)^{\frac{S_0}{cL}} [K_0 - \bar{K} + \frac{cL}{b - d}]. \tag{5d}$$

Thus reorganization is feasible if

$$\frac{cL}{b - d} + (1 + b - d)^{\frac{S_0}{cL}} [K_0 - \bar{K} + \frac{cL}{b - d}] \geq 0 \tag{7}$$

or,

$$K_0 \geq \bar{K} - \frac{cL}{b - d} [1 - (1 + b - d)^{-\frac{S_0}{cL}}] \tag{7a}$$

or, in terms of the required size of the food stock

$$S_0 \geq \frac{1}{\log (1 + b - d)} [-cL \log(1 - \frac{(b - d)(\bar{K} - K_0)}{cL})]. \tag{7b}$$

When the food inventory is exhausted, the capital stock may grow according to the relation

$$K_{t+1} = (a - c) L - R + (1 + b - d) K_t. \tag{8}$$

The initial condition is $K = K^*$ at $t = S_0/cL$ if equation (5b) holds as long as the food inventory lasts.[1] The solution to (8) then is

[1]Here, and in the remainder of this discussion, it is simply assumed that S_0/cL (or whatever expression corresponds to the time available for reorganization) is an integer. The complications of splicing two difference equation regimes at a nonintegral value are irrelevant and will be ignored in the interests of simplicity.

$$K_t = \bar{K} + (1 + b - d)^{t - \frac{S_0}{cL}} [K^* - \bar{K}]. \tag{8a}$$

Thus, at time T, the measure of ease of reorganization is

$$\frac{K_T}{L} - \frac{\bar{K}}{L} = (1+b-d)^{T-\frac{S_0}{cL}} [\frac{-c}{b-d} + (1+b-d)^{\frac{S_0}{cL}} (\frac{1}{L})(\frac{aL+bK_0-dK_0-R}{b - d})] \tag{8b}$$

$$\frac{K_T}{L} - \frac{\bar{K}}{L} = \frac{(1+b-d)^T}{b - d} [-c(1+b-d)^{-\frac{S_0}{cL}} + \frac{1}{L} (aL+bK_0-dK_0-R)]. \tag{8c}$$

To determine the effect of a change in L on the ease or difficulty of reorganization, differentiate (8c) with respect to L, getting

$$\frac{d}{dL} (\frac{K_T}{L} - \frac{\bar{K}}{L}) = \frac{(1+b-d)^T}{b - d} [\frac{R+dK_0-bK_0}{L^2} - \frac{S_0}{L^2} (1+b-d)^{-\frac{S_0}{cL}} \log(1+b-d)]. \tag{9}$$

This is nonnegative if

$$R + d K_0 - b K_0 \geq S_0 \log(1 + b - d)(1 + b - d)^{-\frac{S_0}{cL}} \tag{10}$$

Since the right-hand side is positive, but approaches zero as L approaches zero, this condition will surely be satisfied for some values of L if

$$R > (b - d) K_0 \tag{11}$$

holds, but not otherwise. Condition (11) says that the fixed requirement must be so large that some positive amount of labor is needed in order to meet it at the start of the reorganization period; it cannot be met from the output of capital alone without drawing down the capital stock. Assuming this condition is satisfied, condition (10) can be converted into the following condition on L:

$$L[\log S_0 + \log \log(1+b-d) - \log(R+dK_0-bK_0)] \leq \frac{S_0}{c} \log(1+b-d). \tag{10a}$$

It can be shown that the expression in brackets is positive if reorganization is feasible (or if it is infeasible by a sufficiently small amount).[1] On that assumption, (10a) can be rewritten[2]

$$L \leq [\log S_0 + \log\log(1+b-d) - \log(R+dK_0-bK_0)]^{-1} \frac{S_0}{c} \log(1+b-d). \quad (10b)$$

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[1]This can be demonstrated from (7b), noting that

$$\log\left[1 - \frac{(b-d)(\bar{K}-K_0)}{cL}\right] = \log\left[\frac{a}{c} - \frac{R+dK_0-bK_0}{cL}\right]$$

and using the inequality $\log(\theta - x) < -x$ for $0 \leq x < \theta$ and $\theta < 1$.

[2]This condition becomes more intuitively appealing when interpreted as follows. Let $Y = S_0/cL$, the time available for reorganization. Consider K_T/L as a function of L, T, and Y. It can be seen from (8c) that for $T > Y$, the function can be written in the form

$$\frac{K_T}{L} = \frac{\bar{K}}{L} + h(T)\,\frac{f(L,\ Y)}{L}$$

where $f(L, Y)$ is positive if reorganization is feasible. Differentiating nonessential capital per capita totally with respect to L, it is found that

$$\frac{d}{dL}\left(\frac{K_T}{L} - \frac{\bar{K}}{L}\right) = \frac{h(T)}{L^2}\left[L\left(f_1 + f_2\frac{dY}{dL}\right) - f\right]$$

which is positive if

$$\left(f_1 + f_2\frac{dY}{dL}\right) > \frac{f}{L}.$$

This condition can be read as follows: an increase in L will result in an increase in nonessential capital per capita if the resulting increment in nonessential capital exceeds the previous value of nonessential capital per capita: in computing this increment, it is necessary to consider both the direct increment produced by the additional labor, and the effects of the shortening of the reorganization period. Condition (10b) is a simplified version of this statement, after the following translation:

$$f(L,Y) = \frac{1}{b-d}\left[-cL(1+b-d)^{-Y} + aL + bK_0 - dK_0 - R\right]$$

$$f_1(L,Y) = \frac{a}{b-d} - \frac{c}{b-d}(1+b-d)^{-Y}$$

$$f_2(L,Y) = \frac{cL}{b-d}(1+b-d)^{-Y}\log(1+b-d)$$

$$\frac{dY}{dL} = -\frac{S_0}{cL^2}.$$

The right-hand side represents an "optimum" value of L from the point of view of the "nonessential capital per capita" criterion, in the sense that increases in L will increase the criterion up to that point, and decrease it thereafter.[1] This value is larger, the smaller is c, the larger S_0, and the larger R. If, however, condition (11) is not satisfied, then there is no positive optimum value of L. An increase in L always leads to a decline in nonessential capital per capita, because the decline in the ratios K_0/L and S_0/L dominates the result.

It has been assumed in the foregoing analysis that the fixed requirement R must be met out of current production, rather than out of inventory. The opposite case is now briefly considered.

The value of $\bar{K}$ and the behavior of the system after the food inventory is exhausted are, of course, the same as in the former case. However, as long as inventories last, the capital stock can grow according to the relation

$$K_{t+1} = K_t + aL + (b - d)\, K_t \tag{12}$$

the solution of which is

$$K_t = \frac{-aL}{b-d} + (1 + b - d)^t \left[K_0 + \frac{aL}{b-d}\right]. \tag{12a}$$

The time available for reorganization is now $S_0/cL+R$. Hence,

$$K^* = \frac{-aL}{b-d} + (1 + b - d)^{\frac{S_0}{cL+R}} \left[K_0 + \frac{aL}{b-d}\right] \tag{13}$$

$$K^* = \bar{K} - \frac{R+cL}{b-d} + (1 + b - d)^{\frac{S_0}{cL+R}} \left[K_0 + \frac{aL}{b-d}\right]. \tag{13a}$$

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[1] Of course, the discussion here relates to ease of reorganization, which is hardly an ultimate objective of policy. "Optimum L" is used to mean simply the value at which the curve has a maximum.

Reorganization is therefore feasible if

$$K_0 \geq (1 + b - d)^{\frac{-S_0}{R+cL}} \left(\frac{R + cL}{b - d}\right) - \left(\frac{aL}{b - d}\right) \qquad (14)$$

or

$$K_0 > \bar{K} - \frac{R + cL}{b - d} \left[1 - (1 + b - d)^{\frac{-S_0}{R+cL}}\right] \qquad (14a)$$

or

$$S_0 > \frac{R + cL}{\log (1+b-d)} \left[\log \frac{R + cL}{aL + (b-d) K_0}\right]. \qquad (14b)$$

If S_0 is sufficiently large, reorganization is possible even if $K_0 = 0$, which was not the case under the earlier assumptions.

The condition (corresponding to [10]) under which an increase in L makes reorganization less difficult is

$$R(1+b-d)^{\frac{-S_0}{R+cL}} - (b-d)\ K_0 > \frac{S_0 cL}{R+cL} (1 + b-d)^{\frac{-S_0}{R+cL}} \log (1+b-d). \qquad (15)$$

This inequality cannot be solved algebraically for L. However, a sufficient condition for a positive optimum L is

$$(1 + b - d)^{\frac{-S_0}{R}} \quad R > (b - d)\ K_0. \qquad (16)$$

This condition is not satisfied for values of R close to zero, and in particular it is not satisfied for some values of R that do satisfy the corresponding condition (11). Hence, under some conditions a positive optimum L may exist if the requirement must be met out of production but not if the same requirement could be met from inventory. In addition, it can be shown that if reorganization is feasible under the earlier assumption that the fixed requirement must be met out of current

production, the optimum labor force under that condition is always larger than under the present assumptions.[1] Presumably, the intuitive explanation for this is that the contribution of an additional laborer to the rate of capital formation during the reorganization period is of greater importance when that rate is being adversely affected by a fixed requirement against output. For example, it might happen that a fixed requirement against output made reorganization infeasible in spite of a very large food inventory, because the capital stock could not be made to grow. An increase in L in this situation might make reorganization feasible by making growth of the capital stock feasible; a corresponding benefit from an increase in L does not arise when the fixed requirement can be met from inventory.

Reorganization is always easier, as measured by the $K_T/L - \bar{K}/L$ criterion, when the fixed requirement can be met from inventory than when it must be met out of current output. This proposition, in fact, is involved implicitly in the discussion just above, since the option of meeting requirements from output and maintaining inventories would always exist, and it has been assumed that it would not be exercised. The validity of the proposition is easily explained by reference to the fact that capital has been assumed to be productive, whereas the food inventory is not.[2] Thus the change in the capital stock at time t resulting from using a unit of inventory at time r-1 instead of using it at time r is proportional to

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[1]It is not a simple matter to demonstrate this proposition. Briefly, the argument involves manipulating (10) and (15) so that in both cases the right-hand side is

$$S_0 \log (1 + b - d).$$

It can be shown that the ratio of the left sides of the resulting expressions (10) to (15) is infinity at L = 0 and 1 at L = infinity, and that the ratio declines throughout. Hence the left side of (10) always exceeds that of (15), and thus (10) is satisfied wherever (15) is.

[2]The food inventory in the model, therefore, should be interpreted as an inventory in excess of the amounts required to make the production process function smoothly; the latter would presumably be as productive as fixed capital. Of course, the United States possesses just such an excess inventory, in the CCC stocks.

$$(1 + b - d)^{t-r} - (1 + b - d)^{t-r-1} = (b - d)(1 + b - d)^{t-r-1} > 0.$$

It always pays to "convert" the food inventory into productive capital at the earliest possible date.

The problem of relating the results just developed to the case where p(K/L) is not a linear function will be commented upon in conclusion. The assumption that the productivity of labor is a linear function of the capital-labor ratio is contrary to the law of eventually diminishing marginal returns, and therefore unappealing on theoretical grounds. However, a pessimistic or optimistic linear approximation to the true function could be used as the basis for an a fortiori demonstration that reorganization would or would not be technologically feasible (within the terms of this model). The most appropriate pessimistic approximation would be

$$\bar{p}\,(\frac{K}{L}) = p(\frac{K_0}{L}) + \frac{p(\frac{\bar{K}}{L} - p(\frac{K_0}{L})}{\frac{\bar{K}}{L} - \frac{K_0}{L}}\,(\frac{K}{L} - \frac{K_0}{L})\ , \qquad (17)$$

a line that lies below p(K/L) over the range K_0 to $\bar{K}$, which is crucial from the point of view of the feasibility of reorganization. (See Figure 12.)[1] Of course, the approximation is optimistic outside of this range, and it would therefore not serve as the basis for a pessimistic estimate of ease of reorganization as it has been defined. An obvious choice for an optimistic approximation would be

$$\bar{\bar{p}}\,(\frac{K}{L}) = \bar{p}\,(\frac{K}{L}) + \max_{\frac{K_0}{L} \le \frac{K}{L} \le \frac{\bar{K}}{L}} [p(\frac{K}{L} - \bar{p}(\frac{K}{L})], \qquad (18)$$

a line parallel to $\bar{p}$(K/L) and tangent to p(K/L). If the optimistic approximation indicated that reorganization would be feasible, while the pessimistic approximation indicated the opposite, it would be necessary to use a piece by piece linear approximation of two or more segments in order to resolve the question.

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[1]This statement, and the diagram, are based on the assumption that p" < 0 (diminishing marginal returns).

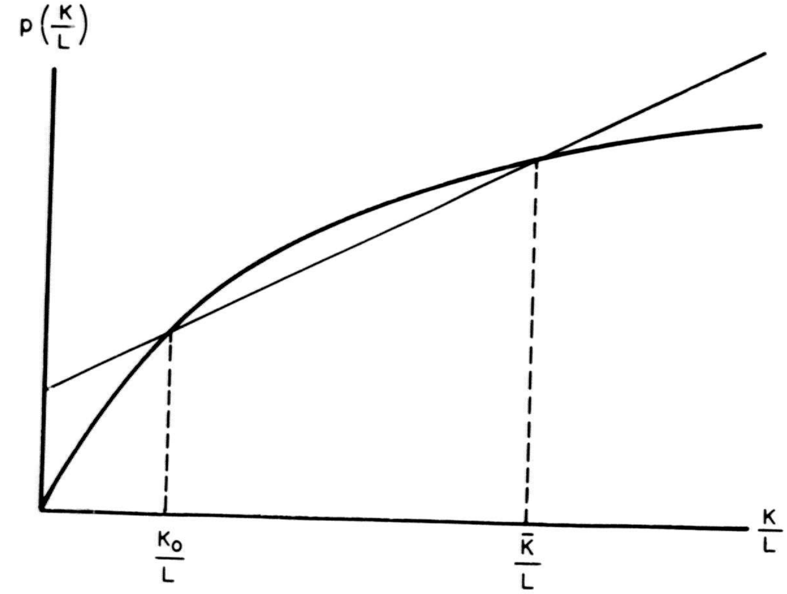

Fig. 12—Technological feasibility of reorganization

Appendix B

THEORETICAL NOTES ON TECHNOLOGICAL STRUCTURE, SELF DEPENDENCE, AND VIABILITY

In this Appendix, the relationships discussed in Section V between the structure of the economy and the feasibility of reorganization and recuperation are examined in more detail and in somewhat more formal terms. The elements of a formal theory of viability and of technological dependence and self dependence are presented and the basic concepts are illustrated with some simple models of viability.

A FORMAL MODEL OF THE VIABILITY PROBLEM[1]

In the terminology of formal mathematical economics, the viability problem can be described as follows: There are $n+1$ distinct, homogeneous resources in the economy, of which one (the $n+1^{st}$) is the labor force (L). Let x_t be a nonnegative n-vector of nonlabor inputs at time t, and y_{t+1} a nonnegative n-vector of output appearing at time $t+1$. The output y_{t+1} is producible from input L_t, x_t if and only if the vector $(L_t, x_t; y_{t+1})$ is in a certain set T, called the "production possibility set" for the economy. Let c_t be a nonnegative n-vector of consumption at time t. The labor force at time $t+1$ is determined by the relation $L_{t+1} = f(L_t, c_t)$. The following assumptions are made about T and f: (1) T is a closed cone. (2) If $(0, 0; y)$ is in T, then $y = 0$. (3) There exists $\bar{L} > 0$, and nonnegative $\bar{x}$ and $\bar{c}$ such that $[\bar{L}, \bar{x}, \lambda(\bar{x} + \bar{c})]$ is in T, $\lambda\bar{L} = f(\bar{L}, \bar{c})$, and $\lambda \geqq 1$. That is, the system can at least reproduce itself from some initial position with a positive L. (4) $f(L, c)$ exists and is nonnegative for all nonnegative L and c, and is a nondecreasing function of L and the elements of c. (5) Changing L_t and all elements of c_t by a given factor will change L_{t+1} by

[1] This subsection provides a formal, abstract characterization of a rather interesting set of problems in the pure theory of production, and defines some concepts (types of self dependence) that appear to be useful in attacking those problems.

the same factor; that is, $f(L, c)$ is linear homogeneous. (6) Labor cannot be increased at an arbitrarily large rate; that is, for some $b > 0$, $f(L, c) \leqq b L$. (7) For some scalar $\epsilon > 0$ and vector $c^* > 0$, $c \leqq c^*$ implies $f(1, c) < (1 - \epsilon)$; that is, some consumption is necessary to maintain the labor force.

In formal terms, the question of whether viability is possible without population loss is the question of whether, given an initial labor force $L_0 > 0$ and an initial endowment y_o of other resources, there are feasible infinite sequences for L_t, x_t, c_y, y_t such that $L_t \geqq L_0$ for all t. (By feasible sequences, is meant that (L_t, x_t, y_{t+1}) is in T, $x_t + c_t = y_t$, and $L_{t+1} = f(L_t, c_t)$, for $t = 0, 1, \ldots.$) By assumptions (1) and (3), such paths are possible for some initial endowments, namely, those proportional to $\bar{L}$, $\bar{x} + \bar{c}$. The character of the set T determines the set of L_0, y_0 combinations that are consistent with viability in this sense. More generally, the properties of feasible sequences for which $\underset{t}{\text{Min}}\ L_t$ is maximized might be examined. (Any sequence for which $L_t \geqq L_0$ is obviously such a maximizing sequence.)

The concepts dependence and weak dependence of resource i on resource j will now be defined.[1] Resource i is dependent on resource j if and only if there exist numbers b_{ij} and d_{ij} such that in all feasible sequences

$$y_{iT} \leqq b_{ij} \sum_{t=1}^{T-1} y_{jt} + d_{ij} \left[\sum_{k=1}^{n} y_{k0} + L_0 \right]$$

and there is no number d_{ij} such that this inequality is satisfied with $b_{ij} = 0$.[2] The rationale of this definition is as follows: The

[1] These definitions are to be taken as applying to the case where either i or j, or both, equals $n+1$, that is, where resource i or resource j, or both, is labor. For this purpose, obviously, the interpretation $y_{(n+1)t} = L_t$ is made.

[2] The second clause is necessary to exclude the unreasonable result that resource i is dependent on everything if there exists no feasible sequence in which y_{iT} becomes arbitrarily large. Unless

intuitive concept of dependence of resource i on resource j is that the production of a unit of i requires, directly or indirectly, at least a minimum input of resource j, or, alternatively, that each unit of i "embodies" at least a certain amount of j, or, alternatively, that it is not possible to have resource i without, in some sense, having resource j first. But, formally, such considerations must be dealt with as (a) mere storage is considered to be a form of production, and (b) the theory relates to sequences with a definite beginning at some time 0, and in the initial endowment there may already be some of resource i, or of other resources that embody some of resource j and may be used to produce resource i. The formal definition therefore states that there may be a certain finite amount of resource i that can be produced out of the initial endowment, but beyond that, further production of resource i requires a certain amount of prior production of resource j.

Resource i is <u>weakly dependent</u> on resource j if and only if there exists a number d_{ij} such that in all feasible sequences

$$y_{iT} > d_{ij} [\sum_{k=1}^{n} y_{k0} + L_0]$$

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otherwise specified, it will be assumed henceforth (assumption (8)) that y_{iT} is unbounded. It is possible, however, to define dependence in a way that is meaningful even if the quantities of some or all resources are bounded in every feasible sequence. The definition is: There exist b_{ij} and d_{ij} such that

$$y_{iT} \leqq b_{ij} \sum_{t=1}^{T-1} y_{jt} + d_{ij} [\sum_{k=1}^{n} y_{k0} + L_0] ,$$

<u>and</u> d_{ij} is less than the least upper bound of

$$y_{iT} [\sum_{k=1}^{n} y_{k0} + L_0]^{-1}$$

taken over all feasible sequences, if such a bound exists. The second clause assures that $b_{ij} > 0$ is in fact necessary in order to bound y_{iT}.

implies $\sum_{t=1}^{T-1} y_{jt} > 0$, <u>and</u> there exist feasible sequences for which

$$y_{iT} > d_{ij} \left[\sum_{k=1}^{n} y_{k0} + L_0 \right] .$$

This definition covers the cases where (intuitively) the production of a unit of i requires, directly or indirectly, some input of resource j, but there is no minimum amount that is required; that is, the input of j per unit of i may be arbitrarily close to zero. Examples of such a relationship can be constructed using the familiar Cobb-Douglas production function.[1] Clearly, if resource i is dependent on resource j it is also weakly dependent on resource j. If resource i is dependent (weakly dependent) on resource i, it will, of course, be said that it is <u>self dependent</u> (<u>weakly self dependent</u>).

One resource may be dependent (or weakly dependent) on another in more than one way. For example, automobiles may be dependent on steel not only because automobiles are made of steel but also because the capital goods used to make automobiles are made of steel and because the steel plants used to make steel are made of steel. Therefore the definition: <u>Resource i is dependent (weakly dependent) on</u>

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[1]That is, suppose the only way of producing resource 1 in the technology is by a process with the production function

$$y_{1(t+1)} = \beta\, x_{2t}^{\alpha}\, x_{3t}^{1-\alpha},\ 0 < \alpha < 1 .$$

Now if either y_{2t} or y_{3t} is zero, $y_{1(t+1)}$ is zero, therefore resource 1 is certainly weakly dependent on both resource 2 and resource 3. However, if $y_{3(T-1)}$ can be increased sufficiently rapidly, y_{1T} may be arbitrarily large even if $\sum_{t=1}^{T-1} y_{2t}$ remains bounded, and similarly if the roles of resources 2 and 3 are reversed. Thus, resource 1 is not dependent on either of them.

resource j, disregarding resource k if and only if it is dependent (weakly dependent) on resource j when the production possibility set is T_k, where T_k is related to T as follows: $(L_t, x_t; y_{t+1})$ is in T_k if and only if (L_t, x^*_t, y_{t+1}) is in T and $x^*_t - x_t = x^*_{kt}\ \delta_k$.[1] That is, i is dependent on j disregarding k if it is still dependent on j even when the fact that k is sometimes required as an input is disregarded.[2] Automobiles, being made of steel, are dependent on steel disregarding everything but steel. On the other hand, automobiles are not dependent on steel plants disregarding steel.

The next definition permits the handling of most of the complications associated with the fact that costless storage may be one of the possible means of "production" of resources one through n. To accomplish this without specifically assuming that costless storage is possible and without characterizing specific storage activities in the technology, it is necessary to deal with the problem that, given a particular (L, x; y) in T, there may be more than one way of splitting x into inputs into storage and into production in the narrow sense.[3] Since it cannot in general be assumed that there is a unique way of interpreting a given input-output combination in terms of storage and actual production, propositions involving reference to the possibility of storage must be framed in terms of the entire set of alternative interpretations.

Let (L, x; y) be in T. The n-vector s is a feasible input to costless storage [given (L, x; y)] if and only if (a) $0 \leqq s \leqq y$

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[1] Here, of course, δ_k is the n-vector with k^{th} element equal to one, and zeroes elsewhere.

[2] The production possibility set T_k does not necessarily describe a possible technology; in particular, condition (2) may not be satisfied; it may be possible to get "something for nothing."

[3] Such nonuniqueness seems improbable if (L, x; y) is efficient; that is, if there is no (L', x', y') in T with $L' \leqq L$, $x' \leqq x$, $y' \geqq y$ and the strict inequality holding for at least one component.

and $x - s \geqq 0$, (b) $(0, s; s)$ is in T and $(0, s_{it}\,\delta_i; s_{it}\,\delta_i)$ is in T for $i = 1, \ldots, n$, and (c) $(L, x-s; y-s)$ is in T. The first condition is that the amount of each good stored is nonnegative and does not exceed either the input or the output; the second says that the storage could be carried on if the "actual production" were not, and could be carried on for any single good independently of the others; the third says that it is possible to produce the output that does not come out of storage from the input that does not go into storage, that is, that the "actual production" implied when s is substracted from input and output is feasible.

The foregoing permits the definition: <u>Resource j is an essential direct input to resource i</u> if and only if there exists a $v_{ji} > 0$ such that for any $(L, x; y)$ in T, $x_j - s_j \geqq v_{ji}\,(y_i - s_i)$, where s is any feasible input to costless storage, given $(L, x; y)$. That is, a certain minimum amount of nonstorage input of j is required for every unit of nonstorage output of i.[1] It is a simple matter to demonstrate that resource i is dependent on each of its essential direct inputs, and on the essential direct inputs to its essential direct inputs, and on the essential direct inputs to the essential direct inputs to its essential direct inputs, and so on. Perhaps it is worth noting that resource i may be dependent on one or more other resources even if it has <u>no</u> essential direct inputs; for example, two or more resources might be perfect substitutes in the production of i, but might have a common essential direct input, in which case resource i would be dependent on that resource.

Other definitions: If S is a set of indices such that for all $i \in S$ and $j \in S$, i is dependent on j and j is dependent on i, S is a <u>loop</u>. If there exists a u_i such that in all feasible sequences

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[1] And, in line with the definition of weak dependence, it may be said that j is a weakly essential direct input to i if $y_i - s_i > 0$ implies $x_j - s_j > 0$.

$$\sum_{t=1}^{T} L_t \leqq u_i \sum_{t=0}^{T-1} c_{it} ,$$

resource i is an essential consumption good. (Here $\frac{1}{u_i}$ may be thought of as the minimum consumption of resource i that is required for a single laborer to survive one period; the inequality represents the summation over t of a condition that the labor force at t+1 is no larger than can be achieved by allocating c_{it} so as to meet this minimum requirement for as many people as possible.) It is easy to demonstrate that any good that is dependent on labor is dependent on every essential consumption good, and on every essential direct input to an essential consumption good, and on the essential direct inputs to those goods, and so on. Hence, in a technology in which every resource is dependent on labor, labor and the essential consumption goods and their essential direct inputs, and their essential direct inputs, and so on, constitute a loop.

A SIMPLE EXAMPLE

To illustrate some of the concepts set forth above, and to suggest some of the implications of self dependence for economic viability, a simple model involving labor and three commodities will now be investigated. The three commodities are: (1) Food (F), which is an essential consumption good (in fact, the function f takes the following simple form: $f(1, c) = 1$ if $c \geqq c^*$, $f(1, c) = 0$ if $c < c^*$, where c is the consumption of food and c^*, obviously, is the per capita subsistence requirement). (2) An intermediate product (S), which is the sole nonlabor input required in the production of food, and has no other use. For purposes of intuitive interpretation, it may be thought of as tractor fuel. (3) A durable capital good (K), which can be used to produce either the intermediate product, or more of itself. Depreciation reduces the capital stock by a fraction d at the end of each time period, regardless of the age composition of the stock.

It is assumed that, in the situations under investigation, the labor force is so large as to make it technologically impossible to employ it fully with the available stocks of K and S. This permits disregarding labor as an input. It is simply assumed that in every process labor is substituted for other inputs to the greatest extent possible.

Let F_t, S_t, and K_t be the stocks of food, intermediate product, and capital existing at time t. The feasible time paths of these variables consistent with meeting subsistence requirements for the initial labor force are those satisfying the difference equations[1]

$$\begin{aligned} F_{t+1} &= F_t + a\, S_t - c^* L_0 \\ S_{t+1} &= r\, k_t \\ K_{t+1} &= (1 + r - d)\, K_t - r\, k_t \, . \end{aligned} \tag{1}$$

In order to make certain relationships stand out more clearly in the discussion that follows, it is assumed that the production functions for newly produced capital and intermediate product are identical.[2] The variable k_t is the amount of capital devoted to producing intermediate product, and it is subject to choice within the range $0 \leqq k_t \leqq K_t$. Of course, F_t, S_t, and K_t must also be nonnegative.

If the system is to be capable of maintaining itself, it must be that $r > d$, that is, capital must be more than capable of maintaining itself. On this assumption, an equilibrium is possible at any nonnegative level of the food inventory, with

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[1]It could, of course, be assumed that costless disposal of any of the three commodities is possible, in which case the feasible paths would be characterized by weak inequalities rather than equalities in (1). However, nothing of interest is lost by assuming that such an option does not exist or is not exercised.

[2]It would suffice to assume that one production function is simply a constant times the other, since in this case an appropriate change of units would make the two identical.

$$\bar{S} = \frac{C}{d}$$

$$\bar{k} = \frac{C}{ar} \tag{2}$$

$$\bar{K} = \frac{C}{a(r-d)} \quad ,$$

where $C = c^*L_0$. These results are, of course, obtained by setting $F_{t+1} = F_t$, $S_{t+1} = S_t$, $K_{t+1} = K_t$ in equations (1).

It is easily seen that each of the three goods is self dependent if labor is an essential direct input in the production of new capital. Capital itself is self dependent disregarding labor, but this is not true of the other two goods. That is, food and the intermediate product are self dependent because they are essential to the support of the labor force, but capital is self dependent even disregarding this fact. Thus capital corresponds to the capacity expansion loop of Section V.

Given initial values F_0, S_0, and K_0, it is possible to avoid a reduction in the labor force below its initial value if and only if it is possible to choose the values of the k_t's in such a way that the F_t's yielded by the equation system (1) never become negative. A negative value would indicate a situation where subsistence requirements could not be met. The more general problem is considered here of choosing the k_t's in such a way that the minimum value of F over time is maximized. If this "maxmin" value is zero, it is just possible to achieve viability by choosing the k_t's according to this maxmin criterion; any other choice of the k_t's would mean a lower, and therefore negative, minimum value of the food stock. On the other hand, if the maxmin value is positive, other choices of the k_t's would also permit viability.

Only initial conditions will be considered such that $K_0 \leq \bar{K}$, and $F^* = \max_{k_t\text{'s}} [\min_t (F_t)] < F_0$. Other cases are uninteresting because the minimum F_t is F_0 or F_1 and the problem of choosing the k_t's is trivial. In the "regular" cases, the structure of the maxmin

solution is as follows: Let $n - 1 = \max t$ (t an integer) such that $F_0 + a\,S_0 - t\,C \geqq F^*$, where $C = c^* L_0$. Then

$$
\left.\begin{array}{l}
F_t = F_0 + a\,S_0 - t\,C \\
F_t = F^*
\end{array}\right\}
\qquad
\left\{\begin{array}{l}
\text{for } t = 1 \ldots n-1 \\
\text{for } t = n \ldots
\end{array}\right.
$$

$$
\left.\begin{array}{l}
S_t = 0 \\
S_{n-1} = \dfrac{C-(F_{n-1} - F^*)}{a} \\
S_t = \bar{S}
\end{array}\right\}
\qquad
\left\{\begin{array}{l}
\text{for } t - 1 \ldots n-2 \\
\\
\text{for } t = n \ldots
\end{array}\right.
$$

$$
\left.\begin{array}{l}
k_t = 0 \\
k_{n-2} = \dfrac{C-(F_{n-1} - F^*)}{a\,r} \\
k_t = \bar{k}
\end{array}\right\}
\qquad
\left\{\begin{array}{l}
\text{for } t = 0 \ldots n-3 \\
\\
\text{for } t = n-1 \ldots
\end{array}\right.
\qquad (3)
$$

$$
\left.\begin{array}{l}
K_t = (1 + r - d)^t\,K_0 \\
K_{n-1} = (1+r-d)^{n-1}\,K_0 - \dfrac{C-(F_{n-1} - F^*)}{a} \\
K_t = \bar{K}
\end{array}\right\}
\qquad
\left\{\begin{array}{l}
\text{for } t = 0 \ldots n-2 \\
\\
\text{for } t = n \ldots
\end{array}\right.
$$

That is, food and the intermediate product are never produced unless a failure to do so would result in a failure to hold F_t above F^* in the next period or two. It is not advisable to build up the food inventory in the early periods in order to defer the date at which the inventory is reduced to F^*; an attempt to do so will ultimately result in the inventory falling to a level lower than F^*.

The following is a sketch of a proof that equations (3) do in fact describe the structure of an optimal solution. First, it is easy to show that $0 \leqq k_t < K_t$ for all t, so the solution is feasible. Also, any optimal solution must have $K_t = \bar{K}$ (and $S_t = \bar{S}$) for $t \geqq n$, otherwise an increase in k_{n-2} could be made, leaving $K_n \geqq \bar{K}$ and increasing F_n, which would contradict the maxmin character of F_n. Next, any reduction in k_t for $t \geqq n-2$ will clearly result in the inventory falling below F^* at time $t+2$, unless some earlier

k_t is larger than indicated in equations (3). Therefore, the only remaining possibilities to be ruled out as optimal solutions are those departures from the program of equations (3) that begin with an increase in some k_t. Such an increase (or increases) leaves K_t smaller at all subsequent dates unless the increase is compensated for by a subsequent decrease (decreases). Such compensation must occur if K_t is eventually to equal $\bar{K}$. However, an increase in k_p compensated by a decrease in k_m, $m > p$, in such a way as to leave K_n, $n > m+1$, unchanged has an effect on F_n given by

$$\frac{d\ F_n}{d\ k_p} = a\ r\ [1 - (1 + r - d)^{m-p}] < 0\ . \tag{4}$$

The explanation of this result is that a reduction in the capital stock by one unit a time p must be compensated for at time m not by the amount of the reduction, but by the amount to which the capital subtracted would have grown by time m, or $(1+r-d)^{m-p}$ times that reduction. As a result, there is a net loss in food production. Therefore, a departure from the program of equations (3) initiated by an increase in a k_t results in lower cumulative food production, and therefore a lower inventory, in the long run. Since under the program (3) the value of F_t for large t is precisely F^*, such a departure means a lower minimum inventory.

Substituting equations (2) and (3) in the relation $K_n = (1+r-d) K_{n-1} - r\ k_{n-1}$ for K_n, K_{n-1}, k_{n-1} (and for the F_{n-1} appearing in the expression for K_{n-1}), the following is derived:

$$\frac{C}{a}\left(\frac{1+r-d}{r-d}\right) + \left(\frac{(n-1)\ C + F^*}{a}\right) = (1+r-d)^{n-1}\ K_0 + \frac{F_0}{a} + S_0\ . \tag{5}$$

This describes the combinations of values of K_0, S_0 and F_0 that will just make it possible to hold the minimum inventory at the level F^*. It must be noted that n is itself a function of F_0 and S_0. But since n does not change continuously as a function of F_0 and S_0, relation (5) may be used to compare the incremental effects on

F^* of increases in K_0 and S_0, treating n as a constant. Differentiating (5),

$$\frac{\partial F^*}{\partial K_0} = a\ (1 + r - d)^{n-1} \tag{6}$$

$$\frac{\partial F^*}{\partial S_0} = a\ .$$

Hence the marginal rate of substitution between K_0 and S_0 is

$$\frac{\dfrac{\partial F^*}{\partial K_0}}{\dfrac{\partial F^*}{\partial S_0}} = (1 + r - d)^{n-1} \tag{7}$$

which is greater than one since $n \geq 2$ for any regular solution. This marginal rate of substitution can be regarded as the ratio of "viability prices," $p_K(o)/p_S(o)$, that is, of prices that express the effectiveness of K_0 and S_0 in increasing F^*. Since n is a discontinuously increasing function of S_0 (an increase of $\bar{S}$ in S_0 increases n by one), this price ratio increases as S_0 increases, and approaches infinity as S_0 goes to infinity. This relation of the viability prices -- a ratio always greater than one and approaching infinity as S_0/K_0 approaches infinity[1] -- may be contrasted with the price ratio that prevails in equilibrium, which is unity.

The foregoing results reflect in part the fact that K is self dependent while S is not (disregarding labor). In part, they reflect

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[1]This characterization of the behavior of the viability prices applies only to the regular cases. The ratio $p_K(o)/p_S(o)$ is zero if $K_0 > \bar{K}$ and $S_0 < \bar{S}$, for in this case $F^* = F_1$ and a small change in K_0 will not affect F^* at all. If both K_0 and S_0 exceed their equilibrium values, $F^* = F_0$ and neither of the viability prices is positive. This may also occur if $K_0 < \bar{K}$, provided that S_0 is so large that $K_t = (1+r-d)^t\ K_0$ exceeds $\bar{K}$ before $F_t = F_0 + a\ S_0 - t\ C$ falls to F_0.

the fact that K is capable of more than reproducing itself, while S is not. The relation of the viability prices to the equilibrium prices depends on the latter consideration. The fact that $p_K(o)/p_S(o)$ goes to infinity as S_0/K_0 goes to infinity, but remains positive as S_0/K_0 approaches zero[1] depends only on the self dependence relations and on the fact that K must be positive in equilibrium. Since S is producible from K there is obviously a limit to the extent to which S can be scarce relative to K, provided only that there is time for the production to take place. Since K is producible only from itself, and is essential in equilibrium, there is no limit to the extent to which K can be more valuable than S, from the point of view of the achievement of viability.

A VARIANT WITH TWO DURABLE CAPITAL GOODS

Now to be considered is a model that is identical with that just discussed except that S is durable instead of being entirely consumed in the production of food. Let u be the proportion of the stock of S that disappears, as a result of depreciation, at the end of the time period. The difference equations corresponding to (1) then become:

$$\begin{aligned} F_{t+1} &= F_t + a\, S_t - C \\ S_{t+1} &= (1-u)\, S_t + r\, k_t \\ K_{t+1} &= (1+r-d)\, K_t - r\, k_t \end{aligned} \tag{8}$$

and the equilibrium values are

$$\overline{S} = \frac{c}{a}$$

$$\overline{k} = \frac{c\,u}{a\,r}$$

$$\overline{K} = \frac{c\,u}{a(r-d)} \;.$$

[1]This, again, refers only to regular cases. It is possible for S_0 to be zero in a regular case, provided that $F_0 > F^* + C$.

This rather minor change in the model makes the determination and description of the maxmin F_t solution a much more complicated matter. Qualitatively new possibilities are introduced. For example, the equilibrium value of K need not be large enough to make it possible to produce the entire equilibrium stock of S in a single period. Therefore, the constraint $k_t \leqq K_t$ may now be binding in some optimal solutions, and the process of raising S to its equilibrium level may take place over several periods, rather than in one or two periods. Also, an optimal solution may involve a process of "buying time:" The k_t's may take positive values for a time so that S and F are increased, then zero values while K grows, then positive values again as the approach to equilibrium is made.[1]

The discussion will be confined, as before, to cases in which $K_0 \leqq \bar{K}$, and $F^* < F_0$. For these cases, it can be shown as before, that an optimal solution always involves S_t, k_t, and K_t taking the equilibrium values shown in (9) and $F_t = F^*$ for all $t \geqq n$, for some n. For, if this were not the case, it would be possible to increase F^* by increasing some k_t, for $t \leqq n-2$.[2] It follows that, given the time n at which equilibrium is first achieved, an optimal solution is a solution that maximizes the cumulative food output to time n, subject to the constraint that $K_n = \bar{K}$, and $S_n = \bar{S}$. For a solution with a higher cumulative food output to time

---

[1]This pattern can characterize an optimal solution because an increase in S_t that leaves S_t below the equilibrium level may increase cumulative food production over a period of time by more than C units; thus allowing an extra period for K to grow to the equilibrium level. An increase of S_t by one unit increases cumulative food production to time n by an amount that comes arbitrarily close to a/u units if $n-t$ is large. (See note 1, p. 191.) Hence an increase ΔS_t in S_t may increase F_n by more than C if $\Delta S_t > u\, C/a$, and still leave S_t less than $\bar{S}$, if $\Delta S_t < C/a$. If $u = 1$, as in the simpler case, this sort of a pattern is clearly impossible.

[2]That some k_t is less than K_t, for $t \leqq n-2$, is implied by the fact that $K_0 \leqq \bar{K}$. If k_t were equal to K_t for $t = 0, \ldots, n-2$, K_n would necessarily be less than $\bar{K}$, considering that $r\, k_{n-1} \geqq u\, \bar{S} = (r-d)\, \bar{K}$.

would have a higher F_n, and therefore, since equilibrium is achieved at time n, a higher F^*.

This last conclusion permits us to deduce some of the properties of a maxmin F_t solution by supposing n to be known and considering instead the simpler problem of maximizing the cumulative food production to time n subject to the condition that equilibrium is achieved at n. This simpler problem is, in fact, a straightforward linear programming problem:

$$\text{Max} \sum_{t=0}^{n-1} a\, S_t \tag{10}$$

Subject to

$$\begin{aligned}
S_1 - r\,k_0 &= (1-u)\,S_0 \\
S_{t+1} - (1-u)\,S_t - r\,k_t &= 0 \quad (t=1,\ldots,n-1) \\
-S_n &= -\bar{S} \\
K_1 + r\,k_0 &= (1+r-d)\,K_0 \\
K_{t+1} - (1+r-d)K_t + r\,k_t &= 0 \quad (t=1,\ldots,n-1) \\
-K_n &= -\bar{K} \\
-K_t + k_t &\leqq 0 \quad (t=0,\ldots,n-1)
\end{aligned}$$

and

$$k_t,\ K_t,\ S_t \geqq 0\ ,\ (t=0,\ldots,n)\,.$$

It is of interest to determine the relationship of the viability prices $p_S(0)$ and $p_K(0)$; that is, to determine the increase in F^* that could be obtained as a result of a one unit increase in S_0 or K_0. For this purpose, it is not the direct problem (10) that is considered but the related "dual problem":[1]

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[1] The discussion that follows assumes familiarity with the standard theorems describing the relationship between a linear programming problem and its dual. See, for example, R. Dorfman, P. A. Samuelson and R. M. Solow, Linear Programming and Economic Analysis, McGraw-Hill Book Company, Inc., New York, 1958, Chapters 3 and 7.

$$\text{Min} \ [(1-u)\ S_0\ p_S(1) + (1+r-d)\ K_0\ p_K(1) - \bar{S}\ p_{\bar{S}} - \bar{K}\ p_{\bar{K}}] . \tag{11}$$

Subject to

$$p_K(n) - p_{\bar{K}} \geqq 0 \tag{11a}$$

$$p_K(t) - (1+r-d)\ p_K(t+1) - p_k(t) \geqq 0 \ (t = 1,\dots, n-1) \tag{11b}$$

$$p_S(n) - p_{\bar{S}} \geqq 0 \tag{11c}$$

$$p_S(t) - (1-u)\ p_S(t+1) \geqq a \ (t = 1,\dots, n-1) \tag{11d}$$

$$- r\ p_S(t+1) + r\ p_K(t+1) + p_k(t) \geqq 0 \ (t = 0,\dots, n-1) \tag{11e}$$

and

$$p_K(t+1),\ p_S(t+1),\ p_k(t) \geqq 0 \ (t = 0,\dots, n-1) . \tag{11f}$$

Inequalities (11a) through (11e) have, of course, a standard interpretation in terms of a condition that the corresponding activity in the direct problem shall not show a profit when the various "inputs" to the activity are valued at the "prices" that are the variables in the dual problem. When the prices are those that yield the solution to (11), each indicates the improvement in the maximand of the direct problem that would occur if the corresponding constraint in the direct problem were relaxed by one unit. Thus $p_K(t)$ and $p_S(t)$ are simply the improvement in the maximand if additional units of K and S somehow became available at time t, $p_{\bar{K}}$ and $p_{\bar{S}}$ are the improvements that would occur if somehow $\bar{K}$ and $\bar{S}$ could be reduced without changing any of the other constants of the problem. Finally, $p_k(t)$ is the increase in the maximand that would occur if it were possible to let $k(t)$ exceed $K(t)$ by one. Of course, $p_k(t)$ is zero if $k(t) < K(t)$ in the solution to (10).

The equality rather than the strict inequality holds in any constraint of (11) for which the corresponding variable in problem (10) appears at a positive level. Hence, in particular, all of the constraints (11b) and (11d) are satisfied with the equality holding

if $K_0 > 0$ and $S_0 > 0$. On this assumption, (11d) can be regarded as a backwards difference equation, the solution to which is:

$$p_S(t) = \frac{a}{u} + (1-u)^{n-t} \left(p_S(n) - \frac{a}{u}\right) \qquad 1 \leqq t \leqq n \cdot \qquad (12)$$

Since $\frac{a}{u}$ is the limit as t goes to infinity of the cumulative food production yielded by a single unit of S made available at some time t_0 and allowed to depreciate,[1] it is intuitively reasonable that $p_S(t) < \frac{a}{u}$ for all t, that is, that the second term on the right hand side of (12) is negative. For if a unit of S available at some time t_0 yields an increase in cumulative food production $\frac{a}{u}$ units as t goes to infinity, it must certainly yield some smaller increase by time n. It can be shown rigorously (taking into account the alternative ways in which the optimal solution to (10) might be altered in response to an increase in S_n) that, in fact,

$$p_S(n) \leqq (1+r-d)^{-1} \frac{a}{u} \cdot \qquad (13)$$

Hence, combining (12) and (13),

$$p_S(t) \leqq \frac{a}{u} \left[1 - (1-u)^{n-t} \frac{r-d}{1+r-d}\right]. \qquad (14)$$

On the other hand, combining (11b) and (11e), it is seen that

$$p_K(t) \geqq (1-d)\ p_K(t+1) + r\ p_S(t+1) \qquad (t = 1,\ldots, n-1). \qquad (15)$$

Invoking this relation for $t = n-1$ and then for $t = n-2$, and substituting $[a + (1-u)\ p_S(n)]$ for $p_S(n-1)$, it is found that

$$p_K(n-2) \geqq r\ a + (1-d)^2\ p_K(n) + [r(1-d) + r(1-u)]\ p_S(n) \cdot \qquad (16)$$

Now, by definition of n, $S_n > S_{n-1}$, and therefore k_{n-1} is positive. This means that the equality holds in (11e) for $t = n-1$, and, since $p_k(n-1)$ is nonnegative, $p_S(n) \geqq p_K(n)$. In place of (16), therefore,

$$p_K(n-2) \geqq r\ a + p_K(n)\ [(1-d)(1+r-d) + r(1-u)]. \qquad (17)$$

---

[1]That is, a/u is the sum of the infinite series $a + (1-u)\ a + (1-u)^2\ a + \ldots$ which is the sequence of food outputs a single unit of S would yield from the time of its production to infinity.

In view of the nonnegativity of $p_k(t)$, (11b) certainly implies

$$p_K(t) \geqq (1+r-d)^{n-2-t}\ p_K(n-2) \qquad \text{for} \quad 1 \leqq t \leqq n-2 . \tag{18}$$

Hence,

$$p_K(t) \geqq (1+r-d)^{n-2-t} \left\{ r\ a + p_K(n)\ [(1-d)(1+r-d) + r(1-u)] \right\} \tag{18}$$

$$\text{for} \quad 1 \leqq t \leqq n-2 .$$

Finally, combining the results (14) and (18),

$$\frac{p_K(t)}{p_S(t)} \geqq \frac{(1+r-d)^{n-2-t} \left\{ r\ a + p_K(n)\ [(1-d)(1+r-d) + r(1-u)] \right\}}{\frac{a}{u}\ [1 - (1-u)^{n-t}\ (\frac{r-d}{1+r-d})]} \tag{19}$$

which implies the weaker result

$$\frac{p_K(t)}{p_S(t)} \geqq (1+r-d)^{n-2-t}\ (r\ u) . \tag{20}$$

Since the viability prices $p_K(0)$ and $p_S(0)$ certainly are related to the prices $p_K(1)$ and $p_S(1)$ by the same relations that hold in general between the prices at t and those at $t+1$, the results (19) and (20) apply for $t = 0$ as well as for $t = 1$ and subsequent times.[1] It is concluded that, as in the simpler case of $u = 1$, the ratio $p_K(0)/p_S(0)$ tends to be large if the time n at which equilibrium is achieved is large. Also, for large n, increasing by one increases the ratio approximately by the factor $(1+r-d)$. However, in contrast to the simpler case, it is possible for the ratio to be less than one if n is small, particularly if u is small. Relation (20) provides an upper bound to the values of n

---

[1]The reason that $p_S(0)$ and $p_K(0)$ are not themselves dual variables is that the maximand shown in (10) has the peculiar character that it depends on one of the constants of the constraint system (S_0) as well as upon the variables. This peculiarity is of no mathematical significance and eliminating it would result in dual inequalities with less obvious interpretations in terms of the original problem.

consistent with $p_K(0)$ being less than $p_S(0)$. A somewhat stronger result can be stated if it is known that $k_{n-1} < K_{n-1}$ and $k_{n-2} < K_{n-2}$; in this case it is easily shown that $p_K(n) \geqq a\ (1+r-d)^{-1}$, and therefore, from (19),

$$\frac{p_K(0)}{p_S(0)} \geqq u\ (1+r-d)^{n-1}\ [1 + \frac{r(1-u)}{(1+r-d)^2}]. \tag{21}$$

The right hand side reduces to the actual value of the price ratio in the case $u = 1$, as may be seen by comparing (21) with (7).

If the economy is just on the margin of viability, that is, if $F^* = 0$, then n is greater than or equal to $\frac{1}{C}(F_0 + a\ S_0)$. Thus, comparing different situations where the economy is on the margin of viability, naturally $p_K(0)$ tends to be large relative to $p_S(0)$ when S_0/K_0 is large.

Appendix C

TECHNICAL NOTES ON THE DERIVATION AND USE OF SURVIVAL CURVES

This appendix is devoted to an exposition of the data sources and procedures involved in the derivation of the survival curves presented in Section VII and to a discussion of the uses and limitations of the curves as indicators of the balance among surviving resources.

DATA SOURCES

The basic data on which the survival curves are based were compiled by the National Resource Evaluation Center of the Office of Emergency Planning from original sources in the 1957 Census of Manufactures and Census Bureau estimates[1] of the 1961 population of the United States. The resources categories for which curves are presented and the unit of measurement for each are as indicated in Tables 10, 11, and 12.

For purposes of describing the geographical distribution of the various resources, the basic information used was the quantity of each resource contained in each ten kilometer square of the ten kilometer grid of the Universal Transverse Mercator (UTM) system. Target areas 20 kilometers square, composed of four 10 kilometer squares with a common corner, were then determined according to the following procedure: The first step was to determine the 20 kilometer target area in the United States containing the largest population, then, from the remaining 10 kilometer squares, the target area containing the next largest population, then the next largest, and so on, until all squares containing more than 50,000 people were accounted for. In this process, of course, some

[1]These estimates were based on the 1950 population census and on subsequent samplings; they were made before the results of the 1960 census became available.

Table 10

INTERPRETATION OF RESOURCE CATEGORIES

Category name	Quantity measured	Unit	100 per cent equals	Minimum value for new square
Population	1961 U.S. population	Persons	181,256,000	50,000
Recovery and military support industry	1957 value added in selected SIC industries[a]	1957 dollars	$57,005,200,000	$50,000,000
Survival industry	1957 value added in selected SIC industries[a]	1957 dollars	$31,573,900,000	$50,000,000
Petroleum refining	1957 crude throughput capacity	Barrels/day	9,471,000 b/d	5,000
Electric power	1962 installed capacity	Kilowatts		500,000
Ports	Number of berths	Berths	3,110	1

Note:

[a]Value added in establishments principally engaged in manufacturing products in the indicated industrial categories. See Table 12 for list.

TABLE 11

STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES INCLUDED IN RECOVERY AND MILITARY SUPPORT INDUSTRY

SIC No.[a]	
19	Ordnance & accessories
2811	Sulfuric acid
2812	Alkalies and chlorine
2824	Synthetic rubber
2826	Explosives
287	Fertilizers
2896	Gases
2897	Insecticides & fungicides
2931-2	Coke & byproducts
2992	Lubricating oils & greases not made in petroleum refineries
301	Tires & inner tubes
331	Blast furnaces, steel works & rolling mills
3291	Abrasive products
3322	Malleable-iron foundries
3323	Steel foundries
333	Primary smelting & refining of nonferrous metals
334	Secondary smelting & refining of nonferrous metals & alloys
3352	Rolling, drawing, & alloying of aluminum
3359	Rolling, drawing, & allowing of nonferrous metals, n.e.c.
3361	Nonferrous foundries
3391	Iron & steel forgings
3392	Wire drawing
3399	Primary metal industries, n.e.c.
3411	Tin cans & other tinware
3422	Edge tools
3424	Files
3425	Hand saws & saw blades
3441	Fabricated structural steel & ornamental metal work
3442	Metal doors, sash, frames, molding, & trim
3443	Boiler shop products
3444	Sheet-metal work
3464-8	Metal stamping, coating & engraving
3491	Metal shipping barrels, drums, kegs & pails
3492	Safes & vaults
3493	Steel springs
3495	Screw-machine products
3496	Collapsible tubes
3497	Gold, silver, tin, aluminum, & other foil
3499	Fabricated metal products, n.e.c.
351	Engines & turbines
352	Agricultural machinery & tractors
3531	Construction & mining machinery & equipment
354	Metalworking machinery
355	Special-industry machinery (except metalworking machinery)
3562	Elevators & escalators
3563	Conveyors & conveying equipment
3564	Blowers, exhaust & ventilating fans
3565	Industrial trucks, tractors, trailers & stackers
3566	Mechanical power-transmission equipment (except ball & roller bearings)
3567	Industrial furnaces & ovens
3568	Mechanical stokers, domestic & industrial
3569	General industrial machinery & equipment, n.e.c.
357	Office & store machines & devices

TABLE 11 (continued)

SIC No.[a]		SIC No.[a]	
358	Service-industry & household machinery	386	Photographic equipment & supplies
359	Miscellaneous machinery parts	387	Watches, clocks, clockwork-operated devices & parts
3612	Carbon & graphite products for use in electrical industry	3913	Lapidary work
3613	Instruments for indicating, measuring & recording electrical quantities & characteristics	3985	Fireworks & pyrotechnics
3614	Motors, generators & motor-generator sets		
3619	Electrical equipment for industrial use, n.e.c.		
362	Electrical appliances		
364	Electrical equipment for motor vehicles, aircraft, & railway locomotives & cars		
366	Communication equipment and related products		
369	Miscellaneous electrical products		
371	Motor vehicles & motor-vehicle equipment		
372	Aircraft & parts		
373	Ship & boat building & repairing		
374	Railroad equipment		
375	Motorcycles, bicycles & parts		
379	Transportation equipment, n.e.c.		
381	Laboratory, scientific & engineering instruments (except surgical, medical & dental)		
382	Mechanical measuring & controlling instruments		
383	Optical instruments and lenses		

Note:

[a]Listing of two or three digit classifications is to be taken as including all higher numbered classifications.

TABLE 12

STANDARD INDUSTRIAL CLASSIFICATION CATEGORIES INCLUDED IN SURVIVAL INDUSTRY

SIC No.[a]	
201	Meat products
202	Dairy products
2031-5	Canning & preserving fruits, vegetables & sea foods
204	Grain-mill products
205	Bakery products
206	Sugar
208	Beverage industries
209	Miscellaneous food preparations & kindred products
2254-5	Knit underwear & glove mills
2322	Men's, youths', & boys' underwear
2328-9	Men's work shirts & other clothing, n.e.c.
2339	Women's & misses' outerwear, n.e.c.
234	Women's, misses', children's, & infants' under garments
2369	Children's & infant's outerwear, n.e.c.
2382	Work gloves & mittens
2385	Raincoats & other waterproof outer garments
2394	Canvas products
2421	Sawmills & planing mills, gen.
2431	Millwork plants
2432	Plywood plants
2433	Prefabricated wooden bldgs. & structural members
2613	Bldg-paper & bldg-board mills
2819	Industrial inorganic chemicals, n.e.c.
2823	Plastics materials & elastomers, except synthetic rubber
2829	Industrial organic chemicals, n.e.c.
283	Drugs & medicines
284	Soap & glycerin, cleaning & polishing preparations, & sulfonated oils & assistants
2861	Hardwood distillation
288	Vegetable & animal oils & fats
2898	Salt
2899	Chemicals & chemical products, n.e.c.
2952	Roofing felts & coatings
2999	Products of petroleum & coal, n.e.c.
302	Rubber footwear
309	Rubber industries, n.e.c.
312	Industrial leather belting & packing
3141	Footwear (exc. house slippers & rubber footwear)
3152	Leather work gloves & mittens
3254	Sewer pipe
3261	Vitreous & semivitreous plumbing fixtures
3262	Vitreous-china table & kitchen articles
3264	Porcelain electrical supplies
3271	Concrete products
3272	Gypsum products
3292	Asbestos products
3321	Gray-iron foundries
3351	Rolling, drawing, & alloying of copper
3393	Welded & heavy-riveted pipe
3421	Cutlery
3423	Hand tools (exc. edge tools, machine tools, files & saws)
3429	Hardware, n.e.c.
3431	Enameled-iron & metal sanitary ware & other plumbers' supplies
3432	Oil burners, domestic & industrial

TABLE 12

TABLE 12 (continued)

SIC No.[a]		SIC No.[a]	
3439	Heating & cooking apparatus (exc. electric), n.e.c.	397	Fabricated plastics products, n.e.c.
3461	Vitreous-enameled products	3983	Matches
3463	Stamped & pressed metal products (exc. automobile stampings)	3984	Candles
3471	Lighting fixtures	3999	Miscellaneous fabricated products, n.e.c.
3481	Nails & spikes		
3489	Wirework, n.e.c.		
3494	Bolts, nuts, washers & rivets		
3532	Oil-field machinery & tools		
3561	Pumps & compressors		
3611	Wiring devices & supplies		
3615	Power & distribution transformers		
3616	Switchgear, switchboard apparatus, & industrial controls		
3617	Electrical welding apparatus		
363	Insulated wire and cable		
365	Electric lamps		
3713	Truck & bus bodies		
3715	Truck trailers		
3716	Automobile trailers		
384	Surgical, medical, & dental instruments & supplies		
385	Ophthalmic goods		
3914	Silverware & plated ware		
3964	Needles, pins, hooks & eyes, & similar notions		

Notes:

[a]Listing of two or three-digit classifications is to be taken as including all higher numbered classifications.

situations were encountered in which the independent choice of 20 kilometer target areas within a given region created patterns that made it impossible to include some heavily populated 10 kilometer squares in target areas. In such situations a simple 20 kilometer grid was adopted, aligned on the square in the region with the largest population. Squares in this grid were designed as target areas if they contained a population of more than 50,000. When all squares qualifying under this procedure were formed, additional squares not in alignment with the others were formed if the population concentration warranted doing so. Fig. 13 illustrates the sort of pattern of target areas that might result from the application of this procedure to a major metropolitan area.

After all of the population target areas were determined, the next step was to create additional target areas wherever the concentration of any resource exceeded the minimum value shown in Table 10 under the heading "Minimum value for new square." The alignment of these additional squares in the 10 kilometer grid was determined according to the criterion that the population included be maximized (subject, of course, to the condition that the concentration of the other resource or resources be included). Finally, the amount of each resource in each target area was determined.

The survival curves of Section VII were derived by ordering the target areas according to the amount of a particular resource they contained and then noting the cumulative percentage of each resource contained in the first N areas in that list. The results were taken as estimates of the destruction that would occur if N target areas were attacked and the attack were designed to destroy the maximum amount of the particular resource in question.

WEAPONS EFFECTS

A square 20 kilometers (12.4 miles) on a side roughly corresponds to the area of severe blast effects from a thermonuclear weapon of about ten megatons yield. Of course, a circle would provide a better approximation to the shape of the region that would suffer at least

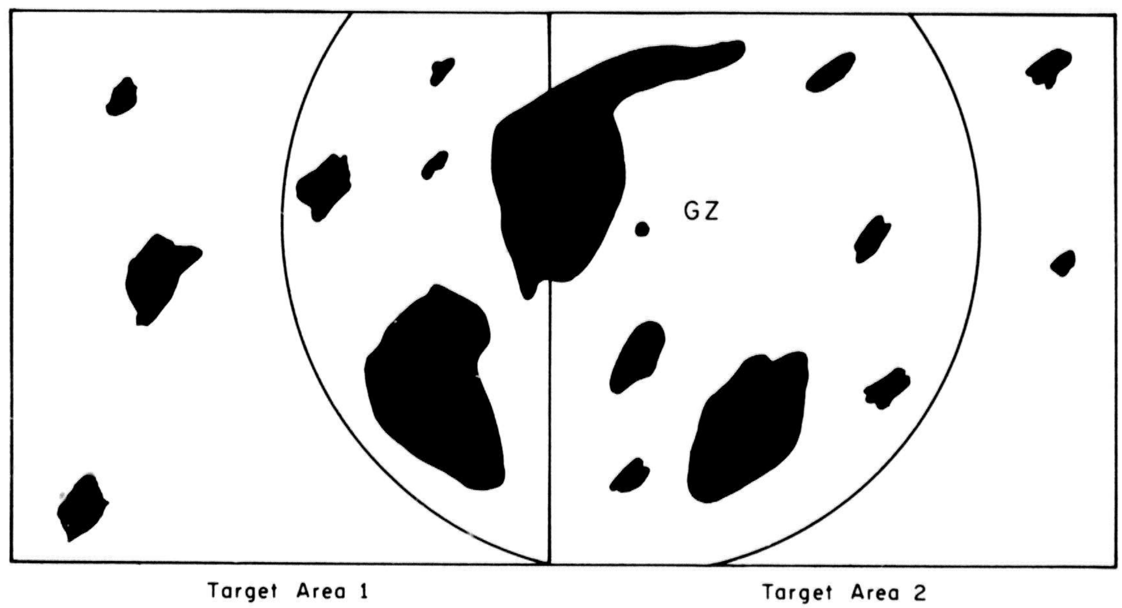

Fig. 13 — Geographical distribution of resource
(illustrative)

a given amount of damage, but the convenience of a square grid was an overriding consideration. The number of ten megaton weapons required to produce severe blast damage over an entire target complex probably corresponds closely to the number of 20 kilometer square target areas into which the complex is divided.

Table 14 shows the peak overpressures that would result at the centers of the sides (10 kilometers or 6.2 miles from ground zero) and at the corners (14.1 kilometers or 8.8 miles from ground zero) of a target area if a multimegaton weapon were detonated at the center, for three weapon yields and two conditions of burst. The range of overpressures shown (1.7 to 13 psi) corresponds to a range of blast effects between moderate damage to a wood frame house to severe or total damage to a steel frame office building.

The amount of confidence that should be placed in the indications provided by survival curves as to the consequences of a particular attack depends on the extent to which the attack pattern and the weapon yields correspond to the assumptions used in deriving the curves.

The curves are most reliable in the analysis of attacks directed at a nonevacuated population, warned of the attack and protected against fallout, with weapons yielding close to ten megatons. This is because population is more of an "area target" than the other resources, the target areas were crudely optimized for population, and the size of a target area corresponds most closely to the area of lethal blast effects from a ten megaton weapon. A comparison of the population loss estimates derived from the list of target areas with more sophisticated estimates[1] of the fatalities that would result from a city attack with ten megaton weapons reveals that the population of the first N target areas exceeds by about 15-20 per cent the

[1] The estimates considered are those presented by Norman A. Hanunian in The Relation of U.S. Fallout Casualties to U.S. and Enemy Options, The RAND Corporation, RM-2747-PR, May 1961.

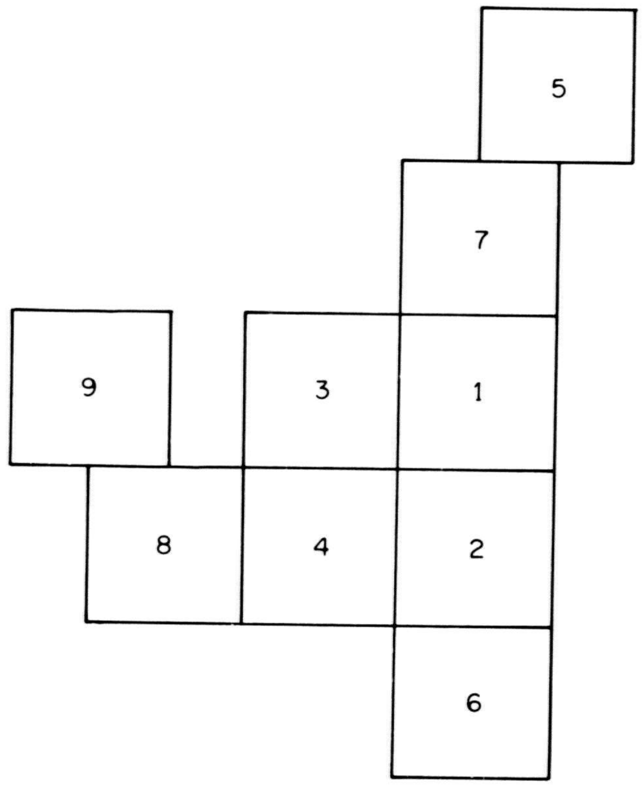

Fig. 14 — Rank of areas by population (illustrative)

Table 13

PEAK OVERPRESSURES AT SIDES AND CORNERS OF TARGET AREA
(ground zero at center of target area)

	5 MT		10 MT		20 MT	
	Air burst[a]	Surface burst	Air burst[a]	Surface burst	Air burst[a]	Surface burst
Sides (6.2 mi. from GZ)	6.5	3.1	9.3	4.6	13	7
Corners (8.8 mi. from GZ)	3.9	1.7	5.4	2.5	7.7	3.7

Note:

[a]Air burst at optimum burst height, that is, at the altitude that maximizes the overpressure at the given range for the given yield.

number of deaths produced by the direct[1] effects of an N weapon attack against cities.[2] Thus the total deaths produced by such an attack may be reasonably well approximated by the population of the N largest target areas, if the population is well protected against fallout. Estimates of total deaths resulting from city attacks of 300 and 3,000 megatons support this conclusion. The population of the first thirty target areas falls in the range of uncertainty for the results of a 300 megaton city attack if population is provided with shelter equivalent to unimproved basements. The population of the first 300 target areas is slightly less than the minimum number of deaths that would be likely to result from a 3,000 megaton city attack, for the same shelter condition.[3]

It is probable that the survival curves somewhat overstate the number of ten megaton weapons required to accomplish a given amount of destruction of any single resource. The geographical distribution of the resource may in some cases be such that a single ten megaton weapon could destroy close to the entire amount of the resource contained in two adjacent target areas, thus "saving" one weapon. Fig. 14 illustrates how the fact that the boundaries between target areas are not drawn with reference to the location of the resources can lead to this result. Since the number of weapons required to destroy a certain amount of a resource certainly does not exceed the minimum number of target areas in which that amount of the resource is contained, there is a definite upward bias in the estimates of the number of weapons required to produce given results.

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[1]That is, the effects of blast and prompt radiations.

[2]This conclusion is based on a comparison of the survival curve population data with Hanunian's Fig. 4, for the ten megaton city attack case. (Ibid., p. 16.)

[3]These remarks are based on a comparison of the survival curve population data with Hanunian's Fig. 5, for the ten megaton city attack case. (Ibid., p. 20.)

In addition, it is likely that a weapon of less than ten megatons yield would in many cases suffice to destroy the entire amount of some resource in a target area. For example, the petroleum refining capacity in a target area may consist of a single refinery, and a weapon with a yield considerably lower than ten megatons would destroy it.

The total megatonnage required to produce a given effect on a resource category may be considerably less than the survival curves suggest. In turn, the destruction in other resource categories resulting from an attack directed at a particular resource might also be substantially less. And, in particular, through appropriate choice of weapon yields and ground zeroes, an attack designed to minimize the per capita availability of some resources might create a much more severe imbalance than the "population avoidance attack" curves of Section VII indicate.

In view of the existence of the sources of bias just mentioned, the survival curves should be regarded as providing an upper bound, rather than an expected value, for the megatonnage required to produce particular levels of destruction in a given resource category. And only in cases where the weapon yields are close to ten megatons and the attacker is assumed not to attempt any sort of avoidance tactic should the curves be taken as reasonably reliable indications of the balance among surviving resources.

Appendix D

RESOURCE CONCENTRATION TABLES

The tables on the following pages are an alternative form of presentation of the data that underlie the survival curves of Section VII (discussed in detail in Appendix C). Tables 14 through 19 show the percentages of six resources contained in various numbers of target areas when the target areas are ranked by each of the resources in turn. Thus the figures in Table 14 show the percentages of population, recovery and military support industry, survival industry, petroleum refining capacity, electric power generating capacity, and port capacity that are contained in the top ten, twenty, and so on, target areas when the areas are ranked by population. Subtracted from 100, these percentages yield the resource survival percentages shown by the population attack survival curves of Section VII. Similarly, Tables 15 through 19 indicate the survival percentages for population and each of the other resources in turn that are presented in the specific resource attack survival curves, but they show in addition the damage that would be inflicted in the other resource categories if the attack were directed at a specific resource other than population. For example, the fourth column of Table 19 shows the percentages of the nation's petroleum refining capacity contained in the first ten, twenty, and so on, target areas when the areas are ranked by the amount of port capacity they contain.

Tables 20 through 25 are similar to the earlier tables, but they show the expected amount of destruction resulting from various numbers of weapons, for various targeting strategies, if the kill probability of an individual weapon against a particular target area is .5. Thus they afford some perspective on the question of how much difference the assumption of perfect delivery of each weapon assigned makes to the number of weapons required to produce the various levels of damage. The assignment of weapons to target areas is determined in the following manner: For example, Table 20 shows the result of an attack directed against population, where each

weapon has a kill probability of .5 against a target area. The first weapon is assigned to the target area ranking highest in population. One-half of the population, and of each of the other resources in that area, is considered to be destroyed by that weapon, the remaining half is reintroduced into the list as if it were a target area containing half the amount of each resource contained in the original top ranked area, at whatever position is warranted by the expected amount of surviving population (one-half the original amount, in this case). The second weapon is assigned to the target area now highest on the list; half of the resources are considered destroyed and half returned to the list, and so on. After all target areas with more than half as much population as the most populous area have been attacked, the remaining half of that area is at the top of the list and a second weapon is assigned to it. This weapon is assumed to destroy half the remaining resources in the area, or one-fourth of the original, and the remainder is again restored to the list, and so on. The result, for any given number of weapons, is the mathematical expectation of the amount of each resource destroyed, if each weapon has probability one-half of killing the area to which it is assigned, and the attack is designed to maximize the mathematical expectation of the amount of population killed. Analogous procedures were followed in deriving the other tables.

TABLE 14

CONCENTRATION OF RESOURCES: AREAS RANKED BY POPULATION

Resource / Number of areas	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	11.9	16.2	15.5	.6	7.2	31.7
20	17.9	26.6	25.1	2.5	10.2	42.4
30	22.0	30.3	30.2	3.3	11.7	51.2
40	25.4	34.8	34.1	8.2	14.0	54.8
50	28.2	39.7	37.4	15.8	16.4	70.7
60	30.6	44.2	40.4	22.2	18.3	74.5
70	32.5	47.4	42.2	25.5	19.5	76.8
80	34.3	49.5	43.6	26.9	20.8	76.8
90	36.0	53.2	46.2	27.8	22.0	77.6
100	37.4	56.4	47.9	30.8	23.4	79.0
120	40.0	58.9	50.0	31.7	24.7	80.8
140	42.2	62.4	52.5	42.4	26.0	81.2
150	43.2	63.5	53.5	45.1	26.9	82.6
160	44.2	65.2	54.5	45.2	27.8	83.4
180	45.9	66.9	56.3	45.5	29.4	85.3
200	47.5	69.7	58.9	47.4	31.2	88.2
250	51.0	73.6	61.5	55.9	33.7	90.7
300	54.0	77.3	64.3	70.5	36.4	93.2
350	56.6	80.1	66.6	72.3	38.9	93.6
400	58.9	82.4	69.2	76.0	41.3	94.5
450	60.9	84.5	70.4	77.5	42.4	94.9
500	62.8	86.1	72.3	77.6	43.7	100.0

TABLE 15

CONCENTRATION OF RESOURCES: AREAS RANKED BY RECOVERY AND MILITARY SUPPORT INDUSTRY

Resource / Number of areas	Popu- lation	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	9.7	21.0	16.0	4.8	7.5	25.2
20	14.5	32.0	24.5	5.9	10.5	33.9
30	16.9	40.1	27.0	9.3	12.5	41.2
40	19.6	47.1	32.3	9.5	14.1	41.2
50	21.6	51.9	33.6	11.6	15.2	46.3
60	23.8	55.9	36.3	20.5	17.7	52.5
70	25.2	59.7	38.3	21.0	18.4	52.5
80	26.7	62.8	41.2	23.9	20.5	59.2
90	28.2	65.4	43.4	24.4	21.3	59.2
100	29.8	67.7	46.0	24.5	21.9	61.7
150	35.8	76.5	51.4	36.0	25.6	65.5
200	39.8	82.2	56.0	39.7	28.4	77.4
250	42.6	86.2	60.1	54.0	32.7	80.8
300	47.3	88.8	64.1	63.4	35.6	83.8

TABLE 16

CONCENTRATION OF RESOURCES: AREAS RANKED BY SURVIVAL INDUSTRY

Number of areas \ Resource	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	10.8	20.5	19.9	1.8	7.1	27.4
20	15.3	27.5	29.2	2.4	9.9	37.5
30	17.7	30.5	35.4	10.7	12.9	49.1
40	19.9	34.8	40.1	14.6	14.7	52.1
50	21.2	36.8	44.0	22.2	16.8	55.8
60	23.3	41.4	47.6	22.8	17.7	56.8
70	25.1	44.5	50.6	25.3	19.7	57.9
80	27.9	46.8	53.2	25.4	20.4	57.9
90	28.8	48.5	55.4	25.4	21.3	57.9
100	30.2	50.8	57.4	25.5	21.7	65.0
150	35.7	57.8	65.4	39.5	26.6	66.0
200	41.1	64.9	70.6	43.0	29.8	73.6
250	44.6	67.4	74.0	47.4	32.9	83.3
300	48.0	70.6	76.7	51.9	34.7	83.6

TABLE 17

CONCENTRATION OF RESOURCES: AREAS RANKED BY PETROLEUM REFINING

Number of areas \ Resource	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	1.4	2.9	2.2	43.3	3.7	6.4
20	2.7	5.1	3.5	63.2	6.1	17.6
30	3.7	6.6	5.4	73.0	6.8	18.0
40	4.9	7.9	6.6	79.9	8.4	18.0
50	5.8	9.3	7.2	84.8	9.1	18.0
60	7.7	11.8	10.4	88.6	11.0	24.1
70	11.2	14.8	15.7	91.7	14.6	44.2
80	12.3	17.4	17.9	94.0	15.3	45.0
90	13.1	18.2	19.3	95.9	15.7	45.0
100	13.5	18.5	19.6	97.2	15.7	45.0
150	17.2	21.8	23.9	100.0	19.6	51.1

TABLE 18

CONCENTRATION OF RESOURCES: AREAS RANKED BY ELECTRIC POWER GENERATING CAPACITY

Resource / Number of areas	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	6.2	12.3	9.2	10.3	11.5	32.4
20	7.9	15.0	12.4	11.1	17.9	38.5
30	10.5	18.8	17.3	17.3	23.5	41.7
40	12.7	21.7	20.1	19.8	28.4	42.8
50	13.8	23.8	21.6	23.8	32.5	48.2
60	15.8	26.9	25.0	23.8	36.1	52.1
70	16.9	28.1	25.8	33.4	39.4	55.9
80	17.9	30.4	28.0	34.6	42.4	55.9
90	19.3	31.1	30.4	38.4	45.0	59.3
100	20.5	33.6	32.5	40.6	47.6	61.0
150	27.2	44.7	39.2	54.5	57.0	67.1
200	33.1	51.8	46.1	60.5	62.9	71.9
250	37.3	56.4	50.9	63.8	65.5	78.9

TABLE 19

CONCENTRATION OF RESOURCES: AREAS RANKED BY PORT CAPACITY

Resource / Number of areas	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	6.9	4.9	9.2	6.9	6.0	55.2
20	11.1	15.0	15.3	13.2	9.9	78.8
30	13.7	17.7	18.8	17.8	11.9	90.3
40	15.9	20.6	21.3	22.5	12.8	97.2
50	16.6	21.5	22.2	29.9	14.2	100.0

TABLE 20

EXPECTED RESULTS OF ATTACK ON POPULATION

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	6.3	8.4	8.6	.4	4.2	20.3
20	9.6	13.2	13.4	1.2	5.9	25.6
30	12.1	17.2	16.8	1.4	7.2	32.7
40	14.2	19.4	19.7	1.8	8.0	35.5
50	15.9	21.5	21.4	2.5	8.8	35.8
100	22.4	31.6	29.9	11.8	13.1	54.7
150	26.7	38.6	35.0	16.3	16.0	60.1
200	30.1	44.0	38.5	20.3	18.2	65.5
250	32.8	47.7	41.7	28.5	20.1	68.7
300	35.1	51.2	44.2	30.0	21.9	70.1
350	37.1	54.1	46.9	31.8	23.6	73.8
400	38.9	56.3	48.3	35.0	24.5	76.1
450	40.6	58.6	50.1	43.5	26.1	78.0
500	42.1	60.5	51.4	46.7	27.0	79.8
550	43.5	62.6	53.0	48.8	28.6	80.5
600	44.7	64.0	54.2	50.6	29.4	81.1

TABLE 21

EXPECTED RESULTS OF ATTACK ON RECOVERY AND MILITARY SUPPORT INDUSTRY

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	5.1	11.3	8.3	2.4	4.1	12.8
20	7.6	17.4	13.3	3.0	5.6	17.8
30	9.0	22.0	14.5	4.2	6.8	18.1
40	11.0	25.7	17.6	4.9	8.0	26.2
50	12.2	29.2	20.3	5.9	9.0	27.0
100	17.1	40.9	26.3	12.7	12.5	35.8
150	20.8	48.9	32.9	15.2	15.5	44.3
200	23.4	54.4	36.0	20.6	17.1	47.2
250	25.7	58.9	39.3	23.6	19.1	52.1
300	28.6	62.7	42.6	25.6	20.8	58.3
350	30.4	65.7	44.7	27.8	21.9	59.6
400	31.6	68.3	46.0	30.2	22.7	62.3

TABLE 22

EXPECTED RESULTS OF ATTACK ON SURVIVAL INDUSTRY

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Popu-lation	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	5.8	9.9	10.4	1.0	4.1	18.1
20	8.5	14.6	15.7	1.3	5.6	23.6
30	10.6	18.7	19.8	1.7	7.0	27.8
40	12.0	20.8	22.9	5.8	8.7	34.1
50	13.1	22.2	25.6	6.0	9.3	37.7
100	17.8	31.4	35.3	14.1	13.4	45.1
150	21.6	36.7	41.7	16.7	15.7	48.6
200	24.0	40.8	46.5	18.9	17.3	53.9
250	26.4	44.9	50.5	24.1	19.5	55.7
300	28.8	47.2	53.6	27.7	21.5	57.2
350	30.7	50.0	56.2	29.9	22.7	60.6
400	32.7	52.7	58.6	30.9	23.8	66.0

TABLE 23

EXPECTED RESULTS OF ATTACK ON PETROLEUM REFINING CAPACITY

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	.7	1.4	1.0	22.6	1.8	3.2
20	1.3	2.2	1.9	34.3	3.1	8.8
30	1.7	3.2	2.3	42.9	3.9	10.4
40	2.0	3.5	2.6	49.0	4.5	12.6
50	2.1	3.7	2.9	53.9	4.9	13.7
100	4.0	6.6	5.0	69.4	7.0	16.0
150	7.3	10.3	10.2	78.1	10.5	29.8
200	8.8	12.9	12.5	83.7	11.7	32.1
250	10.3	14.3	14.8	87.7	13.1	37.4
300	11.2	15.7	16.1	90.5	14.1	38.4
350	11.9	16.3	16.9	92.7	14.7	40.1
400	13.0	17.7	18.6	94.3	15.8	43.7

TABLE 24

EXPECTED RESULTS OF ATTACK ON ELECTRIC POWER GENERATING CAPACITY

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	3.8	6.5	5.6	5.2	6.0	20.6
20	4.4	7.5	6.5	5.7	9.3	24.1
30	5.9	10.6	9.6	6.2	12.2	27.0
40	7.9	13.2	12.3	10.0	14.9	28.8
50	8.1	13.6	12.7	10.6	17.2	30.1
100	11.2	18.9	17.2	20.1	25.9	40.0
150	14.3	23.6	22.6	25.6	32.4	45.6
200	16.8	28.3	26.0	31.6	37.4	50.2
250	20.1	32.3	28.7	36.0	41.4	54.3
300	21.7	35.1	31.6	41.0	44.9	56.6
350	23.7	37.7	34.4	43.0	47.7	58.7
400	25.0	40.1	36.0	46.0	50.2	61.0

TABLE 25

EXPECTED RESULTS OF ATTACK ON PORT CAPACITY

SINGLE WEAPON KILL PROBABILITY = .5

Resource / Number of weapons	Population	Recovery and military support industry	Survival industry	Petroleum refining	Electric power	Ports
10	4.1	2.9	5.7	3.6	3.8	31.0
20	6.0	6.6	8.3	6.1	5.7	45.1
30	7.6	8.9	10.5	8.3	6.8	55.1
40	8.7	10.5	11.9	9.9	7.7	62.1
50	9.8	12.2	13.6	12.1	8.7	68.0
100	13.3	16.9	18.0	17.6	11.1	85.0
150	14.9	19.2	19.9	22.7	12.6	92.6
200	15.7	20.3	21.0	26.5	13.4	96.3
250	16.1	20.9	21.7	28.0	13.8	98.2
300	16.4	21.2	22.0	28.8	14.0	99.1
350	16.5	21.3	22.1	29.2	14.1	99.5
400	16.6	21.4	22.2	29.4	14.2	99.8

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